La Jolla Canyon and Scripps Canyon Bibliography

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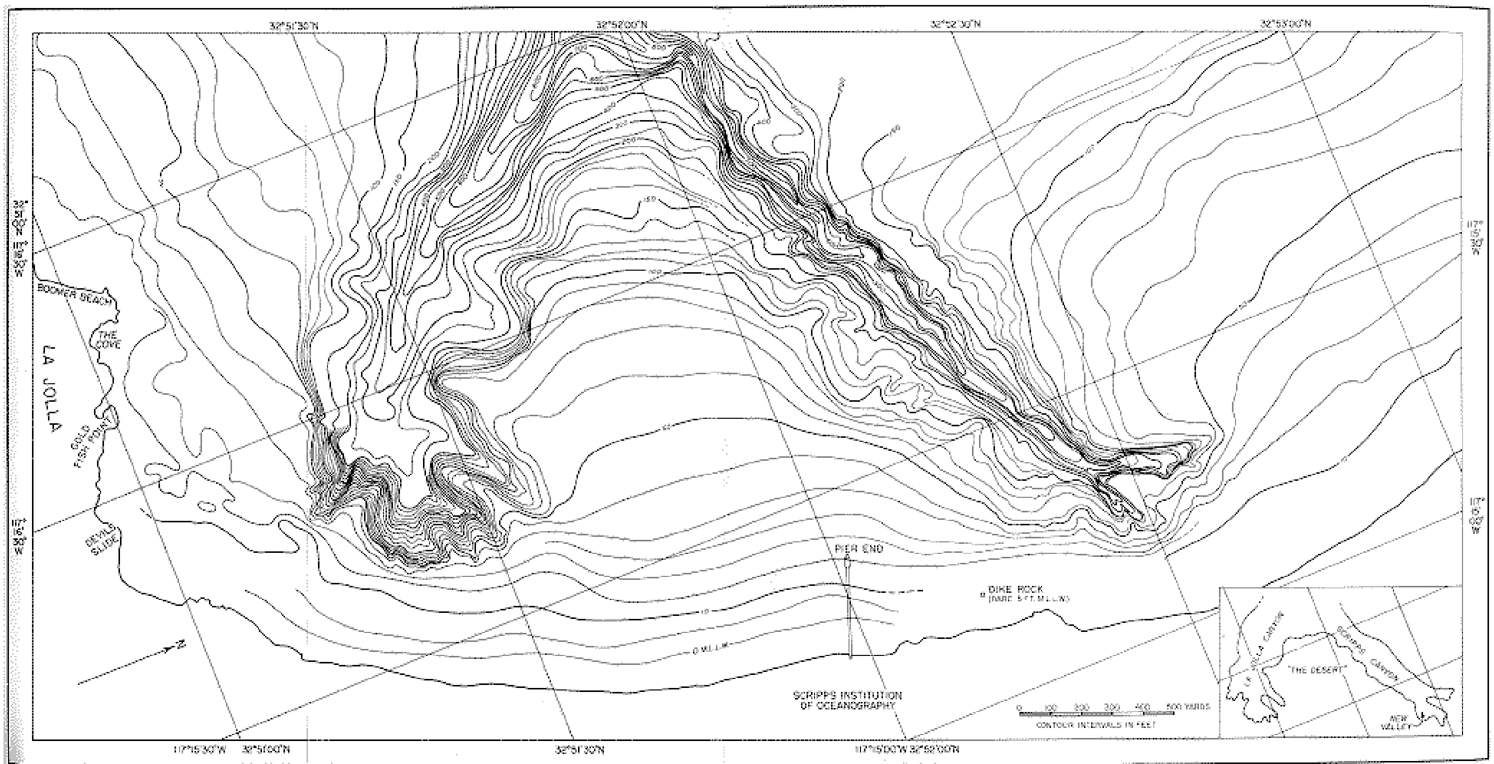

CONTOUR MAP OF SCRIPPS AND LA JOLLA CANYONS

Francis Shepard's classic map of the La Jolla Canyon (left) and Scripps Canyon (right), superceded by modern charting

This bibliography is intended to be comprehensive for published research on the Canyons, including selected non-scientific publications. Annotations are included for many publications so that the reader can learn a lot about the Canyons without chasing down individual publications. The bibliography is arranged from the most recent to the oldest. To assist in reading this bibliography, some background information on the canyons is first provided.

Scripps Canyon (above right) is a narrow gorge about one mile long with three main branches: North, Sumner and South Branches. All three heads can be traced into the coastal cliffs as incised land canyons. Scripps Canyon is cut into calcareous and noncalcareous mudstone and sandstone of the Eocene Ardath Shale (formerly Rose Canyon Shale), including a large amount of conglomerate, as seen in the sea cliffs to the north. Scripps Canyon has precipitous, narrow, sometimes overhanging rocky walls nearly its entire length, with some sections so narrow that submersibles cannot descend to the

bottom. Canyon walls can have scoured and grooved surfaces under the overhanging walls, showing that active erosion is taking place.

A well-recognized feature of Scripps Canyon is the cable stretching across the narrow South Branch of Scripps Canyon. James Stewart, retired Diving Officer of Scripps Institution of Oceanography, said the cable was called Beal's Cable when he arrived at Scripps in 1951, so the cable pre-dates 1951. Alan Beal worked for/with Francis Shepard, a Scripps geology professor. Shepard conducted and published research in La Jolla and Scripps canyons, where much of the early research on formation and geological processes in underwater canyons was done. Beal's Cable was laid by E.R. (Ellis Royal) Cross of the Sparling School of Diving and Underwater Welding in Wilmington, California, who was hired to lay it. Francis Shepard of Scripps would be the obvious candidate for the scientist who arranged for ER Cross to lay that cable. Douglas Inman and Jim Stewart, both said that Beal's Cable had conduit in it and was laid from the old Scripps Pier to a future underwater site to be north of Scripps Canyon to enable connection with measuring instruments on the Scripps Pier. The cable-laying ship's captain became concerned about being too close to shore and mis-laid it across the canyon where it is today, and was not used. When the sand cleared out underwater in 1955 or 1956 exposing the hard bottom, Jim Stewart followed the cable laying along the hard bottom all the way back underwater to just about to the old pier (which was located adjacent to the current Scripps Pier on its north side; the old pier was shorter than the current pier too). Jim agrees with George Spalding's observation on the northern termination of Beal's Cable. George said "...I believe that the cable that transits the South branch terminates at about 80 feet at the junction of the main channel of the Sumner branch and the channel marked on the newer map as the Intermediate Branch. This is the branch that turns south. There is about three feet of cable protruding from the wall there, sticking out of the sand in about the right spot. ..."

La Jolla Canyon (above left) is wider than Scripps Canyon and has at its head a series of gullies cut into semi-consolidated Pleistocene mud with invertebrates boring and burrowing in the mud. Lower down, La Jolla Canyon cuts through Eocene and Cretaceous rocks. La Jolla Canyon has a wide bowl near the head, but a much narrower rock gorge with steep walls is entered at 400 feet.

A **littoral cell** is a stretch of coastline containing a complete sedimentation cycle that cycles sand on and off the beaches. Bounded by the beach on one side and extending seaward to just beyond the area of breaking waves, a littoral cell is the region where wave energy dissipates. Sediments from rivers and from coastal erosion as well as plant detritus and garbage are moved southward along the coastline from Dana Point to La Jolla within the Oceanside Littoral Cell, until these materials encounter the heads of the Scripps and La Jolla Submarine Canyons. These sediments are transported down the canyons, sometimes as rapidly-moving turbidity current flows which further erode the canyon floors and walls. Both canyons have extensive detrital mats, particularly in their shallower reaches, consisting of surfgrass and kelp detritus and supporting a natural

macrofaunal community whose combined density is an order of magnitude larger than that reported anywhere else in the world.

Scripps Canyon joins La Jolla Canyon at a depth of about 900 feet, and the two continue seaward as a rock-walled canyon to about 1,600 feet, where a fan valley cut into unconsolidated sediment is encountered. Both canyons have a series of steps along their axes, some with rock lips with a vertical drop of ten feet or more, whereas others have steep sediment-covered slopes a few feet high, suggestive of landslide scars.

The **submarine fan emptying from La Jolla Canyon into the San Diego Trough** is creased by a steep-sided valley that hooks south. Complex natural levees are present continuously along the right bank of the valley but poorly developed along the left except for the outer third. Terraces are well developed in the central portion adjacent to the inner channel, are intermittent and at variable heights in the middle portion, and are inconspicuous along the outer valley. The valley lacks distinct distributaries, although remnants may exist along the outer part. There are precipitous walls along the outside of the bends of the winding channel. Slumping is taking place actively from these walls and large slump blocks of clay are common on the floor.

How does the sediment mixed with detritus on the canyon bottoms flush out occasionally? Dr. JH van den Berg of the Department of Physical Geography at Utrecht University offers this explanation:

Breaching is defined as the gradual retrogression of a very steep subaqueous slope, steeper than the angle of repose in clean, fine sand. Before particles on a steep slope can be entrained by gravity, their packing has to be changed from a dense to a loose state. As a result negative pore pressures are created in the bed which increase shear resistance and therefore retard erosion. This effect is only important in case the negative pressure is released slowly, thus at relatively low permeability in fine sands combined with a high erosion rate. In the case of gravity, due to shear dilatancy and resulting negative pore pressure, steep slopes up to vertical can exist for some time in fine sands. These breaches retrograde at a velocity in the order of mm/s, dictated by permeability. Two types of breaches are distinguished, (I) with or (II) without a hydraulic jump. Type II breaches retrograde in steep bar slopes. In nature the steep slope may be left behind by the scar of a slide. This type of breach produces a quasi-steady turbidity current. Sustained low energy conditions indicated by thick, massive sand layers preserved in ancient tidal sediments suggest deposition by such a breach generated flow. In contrast to a liquefaction flow slide, a breach retrogrades slowly and may be active for a number of hours. Modern channel bank failures of sands may last for hours, suggesting that breaching is a rather common type of failure in some environments. The periodic 'flushing' of sands from the heads of submarine canyons may also be related to the breaching process. The origin of sustained quasi-steady high-density turbidity currents suggested by the occurrence of massive sandstones in ancient deep-water turbidite successions can be explained in this way. Such canyon breaching fits well with the observation that not all canyon tributaries flush when a storm hits, and that periods of strong waves only occasionally seem to be followed by a flushing event. Since breaching follows from local

slope oversteepening, it can explain the erratic nature of these events in time and space [van den Berg, JH, 2001 personal communication, & Sedimentology 49(1):81-95, 2002].

Extraordinarily high secondary productivity is fueled by the kelp and surfgrass detritus at the head of the La Jolla and Scripps Canyons. What's secondary production? The energy-rich organic material (biomass) created through photosynthesis and embodied within the photosynthetic organisms is consumed and converted into other forms. The biomass of these organisms eating the photosynthetic organisms constitute secondary production. A study examined the surfgrass and kelp detrital mat on the floor of La Jolla and Scripps Canyons. Crustaceans inhabited this mat, achieving densities of more than three million individuals and biomass exceeding one kilogram (dry weight) per square meter at times. The combined maximum density of these animals was 3,240,000 individuals per square meter, an order of magnitude greater than any natural macrofaunal assemblage reported in the literature. Fish prey on these detrital mat crustaceans and are thus the tertiary predators in this ecosystem. Localized productivity hotspots in underwater canyons may be an important energy supply for fish production along some coasts [Vetter, EW. "Hotspots of benthic production." Nature 372(6501): 47, 1994].

La Jolla and Scripps Canyons are among the most studied submarine canyons in the world. Though Monterey Canyon is now more studied, La Jolla and Scripps Canyons were historically the most studied submarine canyons due to their proximity to Scripps Institution of Oceanography. La Jolla Canyon's fan valley was the location of the world's first oceanic drillings, using a drilling barge CUSS I, in March 1961. Five drilling cores to a maximum depth of 1,035 feet below the seafloor were drilled and retrieved at a depth of 3,111 feet in the La Jolla Canyon Fan Valley, where the channel is meandering with raised levee-like ridges and steep banks on the outside of each curve. Contemporary knowledge on the development and maintenance of submarine canyon systems is based on seminal research conducted in these canyons starting in the 1930s.

BIBLIOGRAPHY

Covault, Jacob A., William R. Normark, Brian W. Romans and Stephan A. Graham (2007). "Highstand fans in the California borderland; the overlooked deep-water depositional systems." Geology 35(9): 783-786.

Contrary to widely used sequence-stratigraphic models, lowstand fans are only part of the turbidite depositional record; our analysis reveals that a comparable volume of coarse-grained sediment has been deposited in California borderland deep-water basins regardless of sea level. Sedimentation rates and periods of active sediment transport have been determined for deep-water canyon-channel systems contributing to the southeastern Gulf of Santa Catalina and San Diego Trough since 40 ka using an extensive grid of high-resolution and deep-penetration seismic-reflection data. A regional seismic-reflection horizon (40 ka) has been correlated across the study area using radiocarbon age dates from the Mohole borehole and U.S. Geological Survey piston cores. This study focused on the submarine fans fed by the Oceanside, Carlsbad, and La Jolla Canyons, all of which head within the length of the Ocean-side littoral cell. The Oceanside Canyon-channel system was active from 45 to 13 ka, and the Carlsbad system was active from 50 (or earlier) to 10 ka. The La Jolla system was active over two periods, from 50 (or earlier) to 40 ka, and from 13 ka to the present. One or more of these canyon-channel systems have been active regardless of sea level. During sea-level fluctuation, shelf width between the canyon head and the littoral zone is the primary control on canyon-channel system activity. Highstand fan deposition occurs when a majority of the sediment within the Oceanside littoral cell is intercepted by one of the canyon heads, currently La Jolla Canyon. Since 40 ka, the sedimentation rate on the La Jolla highstand fan has been >2 times the combined rates on the Oceanside and Carlsbad lowstand fans.

Hogarth, Leah J., Jeffrey Babcock, Neal W. Driscoll, Nicolas Le Dantec, Jennifer K. Haas, Douglas L. Inman and Patricia M. Masters (2007). "Long-term tectonic control on Holocene shelf sedimentation offshore La Jolla, California." Geology 35(3): 275-278.

A high-resolution Compressed High-Intensity Radar Pulse (CHIRP) survey reveals shore-parallel variations in the Holocene sediment thickness offshore La Jolla. Sediment thicknesses decrease from >20 m in the south near Scripps Canyon to zero in the north approaching Torrey Pines. In addition to the south-to-north variation in sediment thickness, the transgressive surface observed in seismic lines shoals from Scripps Canyon to the north. Despite these dramatic shore-parallel subsurface changes, the nearshore bathymetry exhibits little to no change along strike. A left jog (i.e., a constraining bend) along the Rose Canyon fault causes local uplift in the region and appears to explain the northward shoaling of the transgressive surface, the decrease in relief on the transgressive surface away from the left jog, and the Holocene sediment thickness variation. This tectonic deformation is shore parallel, and thus the accommodation can be separated into its tectonic and eustatic components.

Magne, R., K.A. Belibassakis, T.H.C. Herbers, Fabrice Ardhuin, W.C. O'Reilly and V. Rey (2007). "Evolution of surface gravity waves over a submarine canyon." Journal of Geophysical Research, Oceans 112(C1): C01002.

The effects of a submarine canyon on the propagation of ocean surface waves are examined with a three-dimensional coupled-mode model for wave propagation over steep topography. Whereas the classical geometrical optics approximation predicts an abrupt transition from complete transmission at small incidence angles to no transmission at large angles, the full model predicts a more gradual transition with partial reflection/transmission that is sensitive to the canyon geometry and controlled by evanescent modes for small incidence angles and relatively short waves. Model results for large incidence angles are compared with data from directional wave buoys deployed around the rim and over Scripps Canyon, near San Diego, California, during the Nearshore Canyon Experiment (NCEX). Wave heights are observed to decay across the canyon by about a factor 5 over a distance shorter than a wavelength. However, a spectral refraction model predicts an even larger reduction by about a factor 10, because low-frequency components cannot cross the canyon in the geometrical optics approximation. The coupled-mode model yields accurate results over and behind the canyon. These results show that although most of the wave energy is refractively trapped on the offshore rim of the canyon, a small fraction of the wave energy 'tunnels' across the canyon. Simplifications of the model that reduce it to the standard and modified mild slope equations also yield good results, confirming that evanescent modes and high-order bottom slope effects are of minor importance for the energy transformation of waves propagating across depth contours at large oblique angles.

Raubenheimer, B., T.C. Lippmann, Steve Elgar and R.T. Guza (2006). "Inhomogeneous Surfzone Bathymetric Change." Eos, Transactions, American Geophysical Union 87(36): OS42C-05.

Bathymetric changes observed between Oct 6 and 13, 2003 along 1500 m of the coast onshore of a submarine canyon a few km north of La Jolla, are compared with predictions of a two-dimensional (2D) energetics-based sediment transport model. During a storm on Oct 9 and 10, 1.5-m-high waves approached the approximately west-facing beach from the northwest at the northern end of the study area and, owing to refraction over the canyon, approached the beach from the southwest at the southern end. The resulting alongshore flows measured in 1- and 2.5-m water depths converged near the middle of the study region, whereas the flows in 5-m water depth diverged from the region. Offshore-directed flows typically were slightly stronger in 1- than in 2.5-m water depth, and were near zero in 5-m water depth. Maximum alongshore and cross-shore flows were roughly 0.5 m/s. Differences between bathymetric surveys conducted prior to and following the storm show that a 1-m high, 200-m long (alongcoast), 50-m wide (cross-shore) wedge of sand accreted in roughly 2.5-m water depth within the region of strong

convergence of alongshore flows. North of the wedge a 0.3-m high ridge of sand accreted along about 1 km of coastline, while south of the wedge bathymetric changes were less than about 0.1 m. Predictions of the bathymetric changes using a 2D (alongshore and cross-shore) energetics model are within 30% of the observations at most locations. The model simulations suggest that the alongshore gradients of the alongshore flows account for roughly 20% of the accretion in the wedge, but caused erosion elsewhere. In contrast to prior studies of sandbar migration during storms, convergence of the cross-shore mean flows was weak, and is predicted to contribute only 10% to the formation of the sandbar and the wedge. Instead, the model suggests the bar and wedge formation result primarily from cross-shore convergence of transport owing to cross-shore gradients of the wave-orbital velocity skewness.

Covault, Jacob A., William R. Normark and Stephan A. Graham (2005). Sea-level and tectonic controls on late Quaternary sedimentation in San Diego Trough, offshore California. Abstracts with Programs - Geological Society of America. Geological Society of America, Cordilleran Section, 101st annual meeting; American Association of Petroleum Geologists, Pacific Section, 80th annual meeting, San Jose, Calif. pp. 34.

High-resolution deep-tow boomer seismic-reflection data are used to characterize late Quaternary (< 50 Ka) deposition in San Diego Trough, a structurally active basin located in the California Continental Borderland. Four modern submarine canyon-channel systems feed sediment into San Diego Trough: Newport, Oceanside, Carlsbad, and La Jolla, from north to south. Newport Canyon, which is more than 50 km north of San Diego Trough, contributes sediment longitudinally, whereas the other three systems are lateral sources. Contrary to typical depositional models in which coarse clastic supply dominates submarine fan deposition during marine lowstand, our examination of deposition in San Diego Trough during Holocene transgression reveals that two of the four canyons remain active. As sea level rose, Oceanside and Carlsbad Canyons were stranded on the outer shelf, deprived of littoral sediment. At present only Newport and La Jolla Canyons have their heads on the inner shelf and continue to feed sediment to their submarine turbidite channel extensions. Within San Diego Trough, all channels extending from these canyons have low relief levees. The juxtaposition of Newport and La Jolla Canyon sediment persisted throughout the latest Quaternary. Displacements along strike-slip faults and related pull-apart depressions and uplifted ridges considerably affected the sediment dispersal of the Newport and Carlsbad canyon-channel systems contributing sediment to San Diego Trough. Deformation approximately 40 km south of Newport Canyon ultimately led to the deflection of Newport channel 20 km to the west. This deflection resulted in Newport channel feeding northern San Diego Trough. Along the eastern side of San Diego Trough, anticlinal folding along a strand of the Coronado Bank fault resulted in blocking progradation of Carlsbad submarine fan and redirecting its sediment to the mid La Jolla Fan area. Late Quaternary deposition in San Diego Trough reveals a complex interplay of river- and littoral drift-fed canyon-channel systems prograding into an elongate structurally active deepwater basin.

Long, Joseph W. and H. Tuba Ozkan-Haller (2005). "Offshore controls on nearshore rip currents." Journal of Geophysical Research, Oceans 110(C12): C12007.

The rip current field resulting from the transformation of surface gravity waves over offshore submarine canyons, specifically Scripps Canyon, is studied. Employing a wave transformation model and a wave-induced circulation model over observed bathymetry we find that wave height variations associated with undulations in the canyon contours cause rip current circulation cells with alongshore spacing of O(100m) even though the nearshore bathymetry displays no variations at these length scales. Further, the predicted rips correspond to observed rip currents during the Nearshore Canyon Experiment (NCEX). Motivated by these results we study the relationship between O(100 m) scale variations in offshore bathymetric contours and the resulting rip current field in the nearshore. To isolate the roles of possible bathymetric features, we construct a series of idealized case studies that include site characteristics found at NCEX that are conducive of rip current development, such as a curved shoreline, an offshore submarine canyon and undulations in the canyon contours. Our results show that the first two components are unable to produce the observed short-scale circulation systems, while wave refraction over undulations in the canyon walls at length scales of O(100 m) provides a sufficient disturbance to generate alongshore wave height variations that drive multiple rip currents for a variety of incident wave conditions. Rips are not generated when the wave period is short, or when the angle of incidence is large. Analysis of the alongshore momentum balances further demonstrates that the rip current locations are also strongly influenced by inertial effects. Hence, nonlinear processes are important within the rip current circulation cell and we find that nonlinear advective acceleration terms balance a large portion of the driving alongshore gradient in the mean water surface elevation in the vicinity of the rip currents with bottom friction accounting for the remainder. Away from the rips, the balance is between the wave forcing and the pressure gradient outside the surf zone and wave forcing and bottom friction inside the surf zone, as expected.

Manam, R. R., S. Teisan, D.J. White, B. Nicholson, J. Grodberg, S.T.C. Neuteboom, K.S. Lam, D.A. Mosca, G.K. Lloyd and B.C.M. Potts (2005). "Lajollamycin, a Nitro-tetraene Spiro- beta -lactone- gamma -lactam Antibiotic from the Marine Actinomycete Streptomyces nodosus." Journal of Natural Products 68(2): 240-243.

A strain of Streptomyces nodosus (NPS007994) isolated from a marine sediment collected in Scripps Canyon, La Jolla, California, was found to produce lajollamycin, a nitro-tetraene spiro- beta -lactone- gamma -lactam antibiotic. The structure was established by complete analysis of spectroscopic data and comparison with known antibiotics oxazolomycin, 16-methyloxazolomycin, and triedimycin B. Lajollamycin showed antimicrobial activity against both drug-sensitive and -resistant Gram-positive bacteria and inhibited the growth of B16-F10 tumor cells in vitro.

Parnell, P. Ed, Cleridy E. Lennert-Cody, Leen Geelen, Laura D. Stanley and Paul K. Dayton (2005). "Effectiveness of a small marine reserve in southern California." Marine Ecology Progress Series 296: 39-52.

While relatively small, the San Diego-La Jolla Ecological Reserve is one of the oldest in California, and it contains giant-kelp-forest, boulder-reef, submarine-canyon and sandy-shelf habitats. We evaluated the effectiveness of this no-take marine reserve and gauged its success according to the goals implicit in its design. To overcome the lack of data prior to its establishment, we employed habitat-specific analyses. Our study comprised 4 components: (1) an historical review of its establishment; (2) a survey of conspicuous species in kelp-forest, submarine-canyon, and boulder-reef habitats; (3) comparisons with historical data; (4) a public survey regarding awareness, knowledge, and support of the reserve. Despite 30 yr of protection, only a few sessile or residential species exhibit positive effects of protection, and most fished species have decreased in abundance inside the reserve. However, the reserve protects the largest remaining populations of green abalone Haliotis fulgens and vermillion rockfish Sebastes miniatus in the area, which therefore represent important sources of larvae. Implementation and enforcement of coastal reserves depends on public support, but the results of the public survey indicated a lack of knowledge of the reserve, highlighting the need for improved public education in this respect. The results of the study reflect the limited value of small reserves and document the inadequacy of inside/outside comparisons as tests of reserve effectiveness when baseline and historical data are lacking.

Perkins, Sid (2005). "Hidden canyons, vast seabed chasms are carved by riverlike processes." Science News 167(1): 9-11.

Discusses turbidy currents in submarine canyons, using Scripps Canyon as one example

Thomson, Jim, Steve Elgar and T.H.C. Herbers (2005). "Reflection and tunneling of ocean waves observed at a submarine canyon." Geophysical Research Letters 32(10): L10602.

Ocean surface gravity waves with periods between 20 and 200 seconds were observed to reflect from the steep-walled La Jolla Submarine Canyon. Observations of pressure and velocity on each side of the canyon were decomposed into incident waves arriving from distant sources, waves reflected by the canyon, and waves transmitted across the canyon. The observed reflection is consistent with long-wave theory, and distinguishes between cases of normal and oblique angles of incidence. As much as 60% of the energy of waves approaching the canyon normal to its axis was reflected, except

for waves twice as long as the canyon width, which were transmitted across with no reflection. Although waves approaching the canyon at oblique angles cannot propagate over the canyon, total reflection was observed only at frequencies higher than 20 mHz, with lower frequency energy partially transmitted across, analogous to the quantum tunneling of a free particle through a classically impenetrable barrier.

Behrens, David W. and Angel Valdes (2004). "A new species of Dendrodoris (Mollusca: Nudibranchia: Dendrodorididae) from the Pacific coast of North America." Proceedings of the California Academy of Sciences 55(13-25): 408-413.

A new species of the genus Dendrodoris, D. azineae, is described based on a specimen collected from La Jolla Canyon, and photographs of animals from Sycamore Banks, Malibu and Carmel Bay, California. Dendrodoris azineae is characterized externally by its unique color, dissimilar to any described species worldwide, having purple gills and rhinophores. Internally, D. azineae differs from other eastern Pacific species in the size of the prostate and bursa copulatrix, and shape and size of the ampulla and the genital atrium. Thus far D. azineae is only known from southern to central California.

Allen, M. James and Ami Groce (2003). "First occurrence of speckletail flounder, Engyophrys sanctilaurentii Jordan & Bollman 1890 (Pisces: Bothidae), in California." Annual report. Southern California Coastal Water Research Project 2001-2002.

Three families (Paralichthyidae, Pleuronectidae, Cynoglossidae) and 29 species of flatfishes have been reported from California. This paper reports the first occurrence of speckletail flounder (Engyophrys sanctilaurentii), the 30th species and the first member of the family Bothidae in California. One specimen of this species (80 mm standard length) was collected by small otter trawl (7.6-m headrope) at a depth of 60 m north of La Jolla Submarine Canyon on August 6, 1998, during the Southern California Bight 1998 Regional Survey. The capture of the speckletail flounder off La Jolla, represents a range extension of 600 km north of its northernmost record near Sebastian Vizcaino Bay, Baja California, Mexico.

Mastbergen, Dick R. and Janrik H. van den Berg (2003). "Breaching in fine sands and the generation of sustained turbidity currents in submarine canyons." Sedimentology 50(4): 625-637.

Natural, moderately loosely packed sands can only erode from the surface of the bed after an increase in pore volume. Because of this shear dilatancy, negative pore pressures are generated in the bed. In cases of low permeability, these negative pressures are released relatively slowly, which retards the maximum rate of erosion. This

effect is incorporated in a new, analytically derived, pick-up function that can explain the observation of gradual retrogressive failure of very steep subaqueous slopes, sometimes more than 5 m high, in fine non-cohesive sands. This process, termed 'breaching' in the field of sediment dredging, may produce large failures in sand bars or river banks. The analytical function that describes the breaching process in fine sand is incorporated in a one-dimensional, steady-state numerical model of turbidity currents describing the spatial development of flow. This model is applied to simulate a large 'flushing' event in Scripps Canyon. Many submarine canyons that extend shorewards into the surf zone serve as active transport conduits for sand from the coastal zone to the shelf or even deeper waters. Sand, transported by wave-induced currents in the nearshore zone, is temporarily trapped in the head of the canyon, until it is transported suddenly downcanyon. Breach retrogradation and the successive evolution in time of the resulting turbidity current in the canyon are predicted in a sequence of discrete steps. Predicted velocities are compared with values measured during a flushing event. Breaching and the turbidity current generated by it should be considered as the mechanism behind large subaqueous slope failures in fine sand. Sand masses trapped in the nearshore heads of submarine canyons such as Scripps Canyon are susceptible to breaching. Computational results of turbidity current velocity near the canyon bed, obtained with a one-dimensional model in which breach growth is incorporated, show satisfactory agreement with quasi-steady flow conditions near the canyon bed measured during a flushing event. This supports the hypothesis that breaching and subsequent ignitive turbidity currents are the main mechanisms of sand removal from the canyon head. Flow evolution and flow duration during a breaching event depend on the geometry and volume of the sand fill. Large breaching events may last for more than a day and might be the origin of some deep-water massive sands.

Normark, William R. and Paul R. Carlson (2003). Giant submarine canyons; is size any clue to their importance in the rock record? IN: Extreme depositional environments; mega end members in geologic time. Geological Society of America Special Paper 370. M. A. Chan and A. W. Archer. Boulder, Colorado: Geological Society of America: 175-190.

Submarine canyons are the most important conduits for funneling sediment from continents to oceans. Submarine canyons, however, are zones of sediment bypassing, and little sediment accumulates in the canyon until it ceases to be an active conduit. To understand the potential importance in the rock record of any given submarine canyon, it is necessary to understand sediment-transport processes in, as well as knowledge of, deep-sea turbidite and related deposits that moved through the canyons. There is no straightforward correlation between the final volume of the sedimentary deposits and size of the associated submarine canyons. Comparison of selected modern submarine canyons together with their deposits emphasizes the wide range of scale differences between canyons and their impact on the rock record. Three of the largest submarine canyons in the world are incised into the Beringian (North American) margin of the Bering Sea. Zhemchug Canyon has the largest cross-section at the shelf break and greatest volume of incision of slope and shelf. The Bering Canyon, which is farther south in the

Bering Sea, is first in length and total area. In contrast, the largest submarine fans--e.g., Bengal, Indus, and Amazon--have substantially smaller, delta-front submarine canyons that feed them; their submarine drainage areas are one-third to less than one-tenth the area of Bering Canyon. Some very large deep-sea channels and turbidite deposits are not even associated with a significant submarine canyon; examples include Horizon Channel in the northeast Pacific and Laurentian Fan Valley in the North Atlantic. Available data suggest that the size of turbidity currents (as determined by volume of sediment transported to the basins) is also not a reliable indicator of submarine canyon size. Incorporates a discussion of La Jolla Canyon and Fan to emphasize the physical-scale relationship between the biggest submarine canyons and turbidite fans and those canyons and fans that are more typical of those mapped in outcrop and borehole studies.

Seymour, Richard (2003). Beach changes in the Oceanside Littoral Cell. Oceans 2003. Celebrating the Past ... Teaming Toward the Future, San Diego, Calif., IEEE, Piscataway, NJ. pp. 1479.

The Oceanside Littoral Cell, extending about 80 km southward from Dana Point in Southern California to Point La Jolla, is one of the most extensively studied coastal regions in the world and among the first to be investigated regionally. It is clearly defined by prominent rocky headlands at either boundary with evidence that there is little sediment exchange with neighboring cells. It is maintained by episodic river borne sediment inputs and erosion from the bluffs that back the majority of the beaches. It also suffers episodic losses of sand from the flushing of a submarine canyon near its southern boundary. The cell contains several coastal lagoons, some with jettied entrances and some connected to the sea episodically, hi addition to these jetties, a system of jetties and breakwater extensions was constructed to protect an artificial harbor at the city of Oceanside, roughly in the middle of the cell. With the exception of these entrances, the cell consists of continuous beaches throughout its length. The paper describes the Oceanside cell geography, the near-coast geology that impacts the beach and the physical forces that result in beach changes. It then discusses the background variability of beach volumes and the positive and negative impacts of human activities on the variations. To accomplish this analysis, the cell is divided into a small number of subregions with similar characteristics and histories. There is limited use of conventional profiles in the discussion. Emphasis is placed on changes to the recreational beach asset, that which is exposed at low tide. Seasonal, long-term and human-induced changes are separated to the extent possible for each of the subregions. Maps and aerial photography are utilized to illustrate the significant attributes

Shanmugam, G. (2003). "Deep-marine tidal bottom currents and their reworked sands in modern and ancient submarine canyons." Marine and Petroleum Geology 20(5): 471-491.

Submarine canyons provide a unique setting for tidal processes to operate from shallow-marine to deep-marine environments. In modern canyons, current-meter measurements at varying water depths (46–4200 m) show a close correlation between the timing of up- and down-canyon currents and the timing of semi-diurnal tides. These tidal bottom currents in submarine canyons commonly attain maximum velocities of 25–50 cm/s. Based on core and outcrop studies of modern and ancient deep-marine deposits, it is proposed here that sand-mud rhythmites, double mud layers, climbing ripples, mud-draped ripples, alternation of parallel and cross-laminae, sigmoidal cross-bedding with mud drapes, internal erosional surfaces, lenticular bedding, and flaser bedding can be used to interpret deposits of deep-marine tidal currents. This approach is an alternative to the conventional approach in which most deep-water traction structures (e.g. climbing ripples and cross-bedding) would be attributed to deposition from turbidity currents. Underwater photographs show active mass flows (i.e. slides, slumps, grain flows, and debris flows) in modern canyons. Box cores taken from modern submarine canyons (e.g. Box core 1 taken from the La Jolla Canyon at a depth of 1039 m) and conventional cores and outcrops of ancient canyon-fill facies (Oua Iboe, Pliocene, Nigeria and the Annot Sandstone, Eocene–Oligocene, SE France) contain deposits of both tidal processes and mass flows. This facies association in the rock record can be used as a criterion for recognizing submarine canyon settings. In a channel-mouth environment, deep-marine tidal deposits are likely to develop elongate bars that are aligned parallel to the channel axis within the channel, whereas turbidites are more likely to develop depositional lobes that are aligned perpendicular to channel axis. Turbidite depositional lobes are much larger than the channel width, whereas tidal sand bars are much smaller than the channel width. Therefore, the wrong use of a turbidite lobe model with sheet geometry in lieu of a tidal bar model with bar geometry will result in an unrealistic overestimation of sandstone reservoirs in deep-water exploration.

Benavides, Stephen (2002). "The Scripps / La Jolla Submarine Canyon, into the abyss." California Diving News 19(1): 16-17.

Describes scuba diving in La Jolla Canyon to see and photograph a squid run

Elgar, Steve (2002). "The Nearshore Canyon Experiment." Eos, Transactions, American Geophysical Union 83(47 Supplement): OS62E-01.

Observations collected in Fall 2003 during the Nearshore Canyon Experiment (NCEX) will be used to test hypotheses about the effect of complex continental-shelf bathymetry on surface gravity waves and on wave-driven circulation. Refraction, diffraction, reflection, scattering, and trapping by abrupt shelf bathymetry can result in dramatic alongshore variations in wave height and direction. Onshore of the irregular bathymetry, alongcoast changes in breaking waves can force complicated circulation, including alongshore flows that reverse direction across the surf zone and along the

shoreline, and strong offshore-directed rip currents that may be an important mechanism for transport of water, sediment, and pollution between the surf zone and inner shelf. Observations for NCEX will be obtained along the southern California coast near two steep submarine canyons (separated alongshore by a few km) that cross the shelf from about 300-m water depth to just seaward of the surfzone near Black's Beach (famous for large waves) and La Jolla Shores (well known as a calm area with small waves). Frequency-directional spectra of incident waves estimated from observations offshore of the canyons will be used to initialize models that predict the effect of the canyons on infragravity waves, swell, sea, and wave-driven circulation. Model predictions will be tested with observations from alongshore arrays deployed near, between, and onshore (including the surf and swash zones) of the canyons. Arrays also will be deployed to investigate wave reflection and scattering from the steep canyon walls, and cross-shore changes in surf and swash zone circulation. Additional instrumentation will be used to study alongcoast changes in wave breaking and set-up, details of surface currents in the surf and swash, and breaking-induced turbulence and dissipation. The NCEX instrument arrays will be designed in collaboration with modelers, and near-real time data will be used to initialize and test model predictions. In addition, model forecasts will be used to guide placement of movable sensors, allowing predictions of nearshore waves and currents to be tested during the observational period.

Holman, R., J. Stanley and C. Paden (2002). "A preliminary look at the NCEX field site using Argus." Eos, Transactions, American Geophysical Union 83(47 Supplement): F715 [OS62E-02].

The Nearshore Canyon EXperiment (NCEX) is scheduled to take place at Black's Beach in the fall of 2003. The primary objectives of this field experiment are to test models for wave propagation across the abrupt topography of the Scripps Submarine Canyon and for the resulting circulation and sediment transport driven by the associated longshore gradients. One component of the sampling scheme is optical measurements of fluid and beach properties, to be made (among others) using a range of Argus techniques. Thus, on October 15, 2001, an Argus Station was installed at the site to begin collection of background data. This talk will summarize the Argus data that has been collected during the initial 1.1 years of collection. The focus will be on describing variations in a set of general site characteristics that will affect NCEX investigators. Most notable will be a morphological description of the site, including statistics of the substantial variability of topographic rips that are commonly observed (and will be a modeling challenge) as well as the scales and genesis of sand bars that have been observed to form on occasion. Other characteristics such as typical surf zone width and width of the dry beach are useful for experimental planning and will be described.

Kaihatu, J.M., K.L. Edwards and W.C. O'Reilly (2002). Model predictions of nearshore processes near complex bathymetry. Oceans 2002 Conference and Exhibition. Conference Proceedings, Biloxi, Miss., IEEE, Piscataway, NJ. pp. 685-691.

Waves undergo significant transformation over complex bathymetry, and the resulting nearshore wave conditions can be sensitive to small changes in the offshore wave forcing. A potential consequence of this transformation sensitivity is large uncertainties in modeled nearshore waves owing to the amplification of the error in the deep water spectra used as initial conditions. In preparation for the upcoming Nearshore Canyon Wave Experiment in La Jolla, a boundary condition sensitivity analysis was performed over the region's submarine canyon bathymetry using the SWAN wave model. The sensitivity analysis included varying the offshore spectrum discretization (frequency and directional bandwidths), the peak period and direction of the spectra, and the frequency and directional spreads. In each case, the magnitude of the spectral variations was governed by expected uncertainties when initializing a nearshore model with a) typical buoy data for the area, and b) global WAM model hindcasts or forecasts. In addition, data from the Torrey Pines Outer Buoy (located 12 km offshore) from the first week of November 2001 were used to initialize the model, and the maximum change seen in the domain over the course of the week were compared to those derived from the sensitivity analysis. The nearshore locations that showed the largest change in wave height over time were also the areas most sensitive to boundary condition errors, and correspond to areas of wave focusing. Errors in the estimation of the peak offshore wave direction were found to have the greatest impact on the accuracy of the nearshore wave predictions. The coarse directional resolution (15 degrees) of deep water spectra provided by the present generation of operational global models is shown to be a significant source of error when handcasting or forecasting nearshore waves over complex bathymetry.

Klimley, A. Peter, Sallie C. Beavers, Tobey H. Curtis and Salvador J. Jorgensen (2002). "Movements and swimming behavior of three species of sharks in La Jolla Canyon, California." Environmental Biology of Fishes 63(2): 117-135.

Six individuals of three shark species, the shortfin mako, Isurus oxyrinchus, great white, Carcharodon carcharias, and blue, Prionace glauca, were tracked near the submarine canyon off La Jolla, southern California during the summers of 1995 and 1997. The duration of tracking ranged from 2 to 38 h per shark. The mode of travel differed in one respect among species. The rate of movement of the endothermic species, the mako and white shark, exceeded that of the ectothermic species, the blue shark. Similarities among species were more common. Firstly, individuals of all three species swam in a directional manner. Secondly, individuals constantly moved up and down in the water column, exhibiting oscillatory or yo-yo swimming. Thirdly, members of the three species swam at the surface for prolonged periods. Finally, the movements of the mako and white sharks were at times loosely associated with bottom topography. We discuss the various adaptive advantages that have been proposed for these behavioral patterns. Oscillatory swimming has been attributed to the following: (1) heating the body in the warm surface

waters after swimming in cold, deep water, (2) alternating between two strata of water, one carrying chemical information as to its source, and deriving a direction to that stratum's origin, (3) conserving energy by quickly propelling oneself upward with many tail beats and slowly gliding downward with few beats, and (4) descending to where magnetic gradients are steeper, more perceptible, and useful to guide migratory movements. At the surface, an individual would be able to swim in a straight line by using following features as a reference: (1) celestial bodies, (2) polarized light, or (3) the earth's main dipole field. Furthermore, an individual would conserve energy because of the greater ease to maintaining a warm body in the heated surface waters.

May, Jeffrey A. and John E. Warme (2002). Subaerial and submarine unconformities and their correlative conformities in a middle Eocene fluvial, shallow-water, and submarine-canyon succession, San Diego, California. Annual Meeting Expanded Abstracts - American Association of Petroleum Geologists. AAPG annual convention with SEPM Houston, TX. pp. 115.

Workers previously interpreted Middle Eocene strata north of San Diego as time-equivalent, interfingering formations. We instead interpret multiple sequence boundaries between and within formations. Landward, a subaerial unconformity separates lagoonal facies of the Delmar Sequence from fluvial deposits of the overlying Torrey Sequence. Basinward, the Torrey becomes estuarine and the contact grades into a correlative conformity. This variation in the sequence boundary indicates that tectonic subsidence increased distally, keeping pace with eustatic fall. Another unconformity--a submarine sequence boundary--separates the Delmar and Torrey sequences from bathyal units of the Ardath Sequence above. The surface is a "sand-on-sand" contact, occurring within a single lithostratigraphic formation. It represents a plucked and stepped submarine-canyon floor, with injection, pry-ups, intraclast-filled scours, and erosional protrusions. Basinward, the sequence boundary cuts out the Delmar and Torrey sequences, placing deep-water deposits onto a kaolinitic paleosol which caps the Mount Soledad Sequence. Tectonic oversteepening probably controlled development of this unconformity. A second submarine sequence boundary occurs within the canyon, eroding into the Ardath Sequence and dividing it from the overlying Scripps Sequence. This surface is a "mud-on-mud" contact. Large slump blocks line the unconformity and represent canyon rejuvenation. Fan deltas probably prograded into and loaded the canyon head during falling sea level, initiating the mass wasting. Thus, variable rates of subsidence, eustasy, and sedimentation along this tectonically active forearc margin created diverse nonmarine and marine unconformities and correlative conformities. Such variations in these surfaces are not adequately depicted in published sequence stratigraphy models and need to be incorporated.

van den Berg, Janrik H., Andre Van Gelder and Dick R. Mastbergen (2002). "The importance of breaching as a mechanism of subaqueous slope failure in fine sand." Sedimentology 49(1): 81-95.

Breaching is the gradual retrogression of a very steep wall, steeper than the angle-of-repose. Breaching produces a sustained quasi-steady, turbidity current, and one source could be sand at the head of a submarine canyon that extends into the surf zone. Scripps Canyon is cited as an example. Such canyon breaching fits well with the observation that not all canyon tributaries flush when a storm hits, and that periods of strong waves only occasionally seem to be followed by a flushing event. Since breaching follows from local slope oversteepening, it can explain the erratic nature of these events in time and space.

Vidal, E.A.G, F.P. DiMarco, J.H. Wormuth and P.G. Lee (2002). "Optimizing rearing conditions of hatchling loliginid squid." Marine Biology 140: 117-127.

Not on the canyons BUT provides more information on the polychaete worm Capitella ovincola, which can infest Loligo opalescens squid eggs in La Jolla and Scripps Canyons. McGowan's 1954 squid article in California Fish and Game said that these large, bright red polychaete worms appeared to be boring through the gelatinous matrix of the egg capsule and not feeding on the developing squid embryos. This 2002 article reports that these worms are present in the sand where the squid eggs are laid, but are not visible when the squid eggs are in early embryonic stages. Migrating from the sand, the worms spread among the egg strands, grow fast, and probably feed on microorganisms in the intermediate gelatinous envelope of the squid egg strands. At first these worms do not appear to disturb the squid embryos, but with time the thickness of the external gelatinous envelope is greatly reduced, leading to its deterioration. This exposes the squid eggs and causes premature hatching with visible external yolk sacs and limited swimming ability. These juvenile squid die shortly after hatching, and a high incidence of premature hatching is not observed in non-infested squid egg strands.

Allen, M. James and Ami K. Groce (2001). "First occurrence of speckletail flounder, Engyophrys sanctilaurentii Jordan & Bollman 1890 (Pisces: Bothidae), in California." Bulletin Southern California Academy of Sciences 100(3): 137-143.

Three families (Paralichthyidae, Pleuronectidae, Cynoglossidae) and 29 species of flatfishes have been reported from California. This paper reports the first occurrence of speckletail flounder (Engyophrys sanctilaurentii), the 30th species and the first member of the family Bothidae in California. One specimen of this species (80 mm standard length) was collected by small otter trawl (7.6-m headrope) at a depth of 60 m north of La Jolla Submarine Canyon on August 6, 1998, during the Southern California Bight 1998 Regional Survey. The capture of the speckletail flounder off La Jolla, California,

represents a range extension of 600 km north of its northernmost record near Sebastian Vizcaino Bay, Baja California, Mexico.

May, Jeffrey A. and John E. Warme (2001). "Sequence stratigraphy of a middle Eocene submarine-canyon complex and related strata, San Diego, California." Abstracts with Programs - Geological Society of America 33(3): 35.

Beach cliffs north of San Diego, California, provide superb three-dimensional exposures of a Middle Eocene submarine-canyon complex. A submarine sequence boundary defines the canyon base. Two sequences comprise the fill; two sequences are truncated beneath. Workers previously interpreted the strata as a succession of time-equivalent, interfingering formations. We instead interpret multiple sequence boundaries between and, in some cases, within formations. The canyon floor is a "sand-on-sand" sequence boundary that lies within a single (lithostratigraphically defined) formation. This surface unconformably separates lagoonal and tidal deposits of the underlying Delmar and Torrey sequences from bathyal units of the Ardath Sequence. The erosional surface is plucked and stepped, and displays injection features, pry-ups, intraclast-filled scours, and erosional remnants protruding up into the overlying fill. Basinward, the sequence boundary cuts out the Delmar and Torrey sequences, placing deep-water deposits onto a kaolinitic paleosol which caps the Mount Soledad Sequence. Internally the canyon complex displays multiple cross-cutting channels on a multitude of scales and with widely diverse lithologies. The lowermost section (Ardath Sequence) comprises amalgamated, pebbly and diffusely laminated sandstones, which fine upward to convolute-bedded fine-grained sandstones, which then grade into laminated to bioturbated silty mudstones. The mudstones fill channels that exhibit a sinuous morphology. Multiple erosional episodes scoured each channel; deposition predominantly occurred during abandonment. A second submarine sequence boundary occurs within the canyon succession, eroding into the Ardath Sequence and dividing it from the overlying Scripps Sequence. This sequence boundary is a "mud-on-mud" contact. Large slump blocks line the base of the sequence boundary and represent canyon rejuvenation. The overlying section displays laterally interconnected coarse-grained channels arranged in a braided architecture. Complete channels contain basal conglomerates overlain by pebbly sandstones that grade upward to interbedded sandstone and siltstone, and finally mudstone. Lithologic predictability within ancient submarine canyons is problematic. Variable channel fills in this Eocene system produce complex vertical and lateral patterns. However, the canyon succession exhibits overall large-scale fining-upward trends above each sequence boundary, yielding a general facies model.

van den Berg, Janrik H. and Dick R. Mastbergen (2001). Breaching in Fine Sands: The Influence of Negative Pore Pressure on Chute-and-Pool Bedforms, Processes of Dike and Bank Failure and the Generation of Sustained Turbity Currents. Program and Abstracts.

7th International Congress of Fluvial Sedimentology, 6-10 August 2001, University of Nebraska-Lincoln, USA., University of Nebraska-Lincoln, USA. pp. 274.

A hitherto neglected factor in the dynamics of fine sand, the influence of negative pore pressure, explains the occurrence of very steep slopes in fine sand, called breaches in the dredging world. Before particles can be entrained by flow or, in case of a steep slope, by gravity, their packing has to be changed from a dense to a loose state. As a result negative pore pressures are created in the bed which increase shear resistance and therefore retard erosion. This effect is only important in case the negative pressure is released slowly, thus at relatively low permeability in fine sands combined with a high erosion rate. In case of flow over a horizontal bed incorporation of this effect in a pick-up function leads to an erosion equation that shows a maximum shifting from fine sand to coarser grades with increasing flow velocity. In case of gravity, due to shear dilatancy and resulting negative pore pressure steep slopes up to vertical can exist for some time in fine sands. These breaches retrograde at a velocity in the order of mm/s, dictated by permeability. Two types of breaches are distinguished, (I) with or (II) without a hydraulic jump. Type I is found in series of bed forms formed at high Froude numbers. These bedforms, called cyclic steps, can be considered as an adaptation of chute-and-pool bedforms in fine sand. Type I breaches also develop as a single step in the first stage of the bursting of a sand dike. The magnitude of cyclic steps increases with discharge and flow energy. Type II breaches retrograde in steep bar slopes. In the dredging practice the required steep slope is initiated by suction. In nature the steep slope may be left behind by the scar of a slide. This type of breach produces a quasi-steady turbidity current. Sustained low energy conditions indicated by thick, massive sand layers preserved in ancient tidal sediments suggest deposition by such a breach generated flow. In contrast to a liquefaction flow slide a breach retrogrades slowly and may be active for a number of hours. Modern channel bank failures of sands may last for hours, suggesting that breaching is a rather common type of failure in some environments. The periodic 'flushing' of sands from the heads of submarine canyons may also be related to the breaching process. The origin of sustained quasi-steady high-density turbidity currents suggested by the occurrence of massive sandstones in ancient deep-water turbidite successions can be explained in this way, as will be shown by a computation for Scripps Submarine Canyon.

Winslow, Kyle Thomas (2001). Sediment transport by turbidity currents. PhD dissertation, University Of California, Berkeley.

Complete field equations have been established for turbidity current flow. A Modified Three Equation Model has been developed to predict the fate of turbidity currents. Particular attention has focused on the impacts of increased sediment concentration on the field equations and the numerical predictions. Functional relationships for closure hypotheses have been chosen after careful review. Previous investigations have invoked the dilute suspension approximation for sediment concentrations up to a few percent by

volume. Experimentally derived relationships for the effect of sediment concentration on settling velocity show that the dilute suspension approximation is not necessarily valid, even at these low concentrations. Results show that initial conditions, such as current height, velocity, and sediment concentration, have a short-lived effect on model predictions. Channel properties, such as slope and bed friction, control the long-term evolution of turbidity currents. The Modified Three Equation Model is highly sensitive to the closure relationships. Properties of the fluid-sediment mixture, such as kinematic viscosity and sediment grain size, can lead to predictions of contrary fates for turbidity currents. In application to Scripps Submarine Canyon, the Modified Three Equation Model predicts a turbidity current with a smaller acceleration than the current predicted by the Parker Three Equation Model. Turbidity current flow is most sensitive to the sediment entrainment function. The steep nature of this function leads to extreme changes in the predicted sediment entrainment rate for minor changes in the input parameters. Unfortunately, these input parameters include the settling velocity and the shear velocity, two properties of the fluid mixture that are difficult to ascertain with a high level of accuracy. Continued effort needs to focus on this relationship. The Modified Three Equation Model does not account for shear at the upper interface of the turbidity current. This needs to be addressed. Future laboratory investigations could also provide much needed data against which to test formulations for sediment entrainment, near-bed sediment concentration, and water entrainment, and the effects of ambient currents on turbidity currents.

Bunton, William J. (2000). Death of an Aquanaut. Flagstaff, Arizona: Best Publishing.

Discusses the author's experiences with the second and third phases of the US Navy's Sealab project. Sealab II was sited at 205 feet near Scripps Canyon; the author was a participating aquanaut in the third team. Saturation dives were conducted at various depths down to 300 feet in Scripps Canyon.

Garfield, Judith Lea (2000). The San Diego-La Jolla Underwater Park Ecological Reserve: La Jolla Shores & Canyon. La Jolla: Picaro Publishing.

Indispensable photo identification guide for marine life commonly seen by divers in La Jolla Canyon and on the inshore sandy flats. Inside cover has a map of La Jolla Canyon with some named areas: North Wall Point; Gorgonian Gardens; Vallecitos Point.

Warme, John E. (2000). "Active margin sequences and submarine canyon facies models." AAPG Bulletin 84(11): 1882.

Superb lower and middle Eocene forearc facies in northern San Diego County, exhibit three stratigraphic sequences that exhibit shoreline and shallow marine facies

(Delmar/Torrey sequence) unconformably overlain by submarine canyon deposits (Ardath and Scripps sequences). Delmar/Torrey facies include fan-delta, lagoon, barrier beach, and marine shelf environments, backed by alluvial-fan complexes. This sequence contains suites of sedimentary structures, fossils, and trace fossils characteristic of the now-familiar proximal facies models. In contrast, the large scale of submarine canyons and their sedimentary fills has inhibited development of applied models for them. The study area provides rare, continuous exposures that can be applied to subsurface exploration and development. They show that the Delmar/Torrey sequence is separated from the overlying Ardath submarine canyon facies by a major sequence boundary and facies shift. This unconformity represents the floor and margins of the fossil "Eocene Torrey Submarine Canyon." The submarine canyon facies model includes a basal massive sandstone, overlain by crosscutting marine channels with unpredictable heterolithic fill. The channels contain active-channel conglomerates, diverse sandstones and siltstones, and abandoned-channel mudstones, collectively termed "variegated fill." A second sequence-bounding unconformity caps these channels, overlain by the conglomeratic Scripps sequence. Surprisingly, age dating of the lower canyon boundary and the canyon fill strongly suggests that their development was driven primarily by eustasy, even though the regional setting was a tectonically active forearc.

Peakall, Jeff, Ben Kneller and Bill McCaffrey (1999). "A classic submarine canyon analogue revisited; high-resolution architecture of the La Jolla Group, San Diego." AAPG Bulletin 83(8): 1332.

The Black's Beach section of the Early to Middle Eocene La Jolla Group is a magnificently exposed and largely untectonised example of an ancient submarine canyon fill. This classic section has been interpreted in terms of a submarine canyon model which has remained largely unmodified since the late 1970's. We have undertaken detailed architectural analysis in terms of both facies and geometries using photomontages compiled from helicopter flights. This has provided an adequate base for high-resolution architectural mapping of the 6.9 km by 100 m section. Lithofacies and erosional surfaces were superimposed onto these templates, and supplemented by detailed logging through incised ephemeral stream sections. The resulting digitised architecture maps allow quantitative assessment of the geometries, abundances and distributions of individual facies. The facies analysis permits the recognition of hitherto undescribed or under-recognised processes that control the fill in the Black's Beach section, and which may be more generally applicable to submarine canyon reservoirs. The interaction of flow with topography can be clearly demonstrated at a number of levels and scales within the fill, suggesting that spatially non-uniform turbidity current models can be applied usefully to submarine canyon deposits. Additionally, prominent slide units, on the order of 10's to 100's of metres, testify to the importance of post-depositional mass movement processes within the finer-grained canyon deposits. Evidence is presented for the importance of tidally influenced currents in controlling some sedimentation in the canyon fill. Existing interpretations of high sinuosity meandering channels and braided channels are reinterpreted in the light of the new dataset and through comparison with studies of

modern channel systems. There is considerable debate as to the variation in age along the Black's Beach transect. Both the benthic foraminifera and nannoplankton show an apparent "younging" trend from the canyon edge in the north to a more central canyon position in the south, however, the magnitude of this variation varies between the nannoplankton and the forams. Lohmar (1978) interpreted the foraminifera data as being predominantly facies, not age related, whilst the nannoplankton data have been interpreted purely in terms of age (May, 1982). However, the presence of large numbers of slide sheets may complicate the age relationships. A comprehensive dating program is being undertaken using nannoplankton, and subsampling successive slide sheets, in order to improve both the age relationships and subsequent reconstructions of the submarine canyon.

Vetter, Eric W. and Paul K. Dayton (1999). "Organic enrichment by macrophyte detritus, and abundance patters of megafaunal populations in submarine canyons." Marine Ecology Progress Series 186: 137-148.

Submarine canyons can provide large quantities of food in aggregated form on the deep-sea floor by acting as conduits for marine macrophyte production produced in the intertidal and shallow subtidal zone. Longshore transport delivers substantial quantities of macrophyte detritus from surf-grass Phyllospadix torreyi, kelps Macrocystis pyrifera and Egregia menziesii, and other macroalgae to the heads of Scripps and La Jolla Canyons. Strong tidal and gravity currents distribute this material throughout much of the canyon system, where it is utilized as food and habitat by benthic fauna. Video data taken from remotely operated vehicles and submarines were used to evaluate differences in detrital cover and megafaunal abundance in the canyons, and at nearby reference stations. Within the canyons dense mats of detritus were common down to 550 m, and M. pyrifera holdfasts were observed at 700 and 900 m. Virtually no drift material was observed out of the canyons. Comparisons of megafaunal invertebrates in and out of the canyons revealed generally higher densities at non-canyon sites due to large numbers of urchins. Species richness of all megafauna and abundance of non-urchin megafauna were greater in the canyons than out. It is likely that urchin abundance in canyons is reduced through disturbance by currents and detrital flows in the canyons. Species richness and abundance of fishes were greater in the canyons at all depths for which comparative data were available (100 to 500 m). From 150 to 200 m in Scripps Canyon, juvenile Pacific hake Merluccius productus were so abundant at times that their bodies obscured visibility. Turbot Pleuronichthys sp. and zoarcids Lycodes pacifica were also abundant in Scripps Canyon from 100 to 300 m. Data from this study support the hypotheses that macrophyte detritus covers large areas of the La Jolla and Scripps Canyon axis, and that megafaunal abundance is associated with detritus at both large and small spatial scales.

Valdes, Angel and David W. Behrens (1998). "A new species of Doriopsilla (Mollusca, Nudibranchia, Dendrodorididae) from the Pacific coast of North America." Proceedings of the California Academy of Sciences 50(13): 307-314.

A new species of the genus Doriopsilla, D. spaldingi, is described on the basis of four specimens collected from La Jolla. This new species is characterized externally by an iridescent blue band around the mantle margin. Internally, D. spaldingi differs from other eastern Pacific yellow species in lacking a pyloric gland, having a very long vagina, an elongate, almost tubular, prostate and in the penial hooks morphology. Additional information on the distribution and natural history of this species is provided. Thus far D. spaldingi is only known from southern California and the northwestern extreme of Mexico.

Vetter, Eric W. (1998). "Population dynamics of a dense assemblage of marine detritivores." Journal of Experimental Marine Biology and Ecology 226(1): 131-161.

Accumulations of macrophyte detritus provide food and refuge for a dense (up to 3,500,000 individuals per square meter) assemblage of amphipod and leptostracan crustaceans in Scripps Canyon. The objective was to determine how the physical environment and biological interactions limit these populations that rarely, if ever, appear to be food-limited. Preliminary observations suggested that the detritus-crustaceans would incur significant losses during the Winter, resulting from wave disturbance. Predation by dense schools of fishes associated with this habitat also appeared to be important. Laboratory and field experiments demonstrated that the detritus provided an effective refuge for the crustaceans. Predation rate of fishes upon detritus-associated crustaceans increased as the density of prey populations increased and/or as the thickness of the detritus mat was reduced (increasing number per cubic meter but not per square meter). Density of the mat crustaceans fluctuated seasonally, being greatest in the Winter and Spring following storms that eliminated large portions of the habitat. Few animals appeared to be directly eliminated by the storm disturbance. The important effect of storms was to reduce the quantity and quality of the detritus refuge by concentrating the crustaceans into smaller patches with less detrital cover. During the calm summer months the bacterium Beggiatoa sp. spread out over large portions of the detritus mat. Beneath the bacteria oxygen concentration was reduced, and infaunal density was two orders of magnitude lower than in unaffected portions of the mat. The summer increase in bacterial cover constituted a biological disturbance that functionally reduced the habitat area available to the mat fauna and left them more vulnerable to predation. Secondary production in the detrital mats is among the highest reported from natural environments. This is possible because the mat crustaceans are unable to graze down their food supply (detritus and associated microbes). The refuge provided by the detritus for large population of invertebrates also is crucial; larger refugia translated into increased carrying capacity which allowed both greater population sizes and production, much of which became available to fishes. Most marine ecosystems are supported by allochthonous material that enters food webs via detritivores. Seafloor features that collect detritus constitute an important source of patchiness over a wide range of scales

because detrital delivery is governed by physical processes. The La Jolla/Scripps Canyon system, by accumulating organic debris, provides a large food source from shallow to continental slope depths. This resource supports large numbers of fishes and presumably increases local production in higher trophic levels.

Vetter, Eric W. and Paul K. Dayton (1998). "Macrofaunal communities within and adjacent to a detritus-rich submarine canyon system." Deep-Sea Research II 45(1-3): 25-54.

Macrofaunal abundance, biomass, diversity and species assemblages within Scripps and La Jolla submarine canyons are compared with those on the nearby continental shelf and slope. Within the canyons, organic enrichment by macrophyte detritus was evident from canyon heads down to 550 meters, and evidence of strong currents (coarse sediment) was found down to 700 meters. Infaunal density and biomass were higher in the canyons than outside at all depths where comparative data were available. Infaunal assemblages in canyons were distinct from those at reference stations. Both the canyon and non-canyon samples showed community differentiation with depth. Species diversity was generally high, but decreased with depth outside of canyons and increased with depth within the canyons. Low diversity at shallow depths within the canyon is attributed to a combination of organic enrichment and physical disturbance. Submarine canyons are commonly found to contain distinct species assemblages or higher faunal densities and/or biomass than nearby non-canyon regions at similar depths. Canyons are regular features along most ocean margins and appear to be important as sites of enhanced secondary production, provide diverse habitats, and act as conduits of coastal detritus to the deep sea.

Zhenzhong, Gao, Kenneth A. Erikson, He Youbin, Luo Shunshe and Guo Jianhua (1998). Deep-water traction current deposits : a study of internal tides, internal waves, contour currents and their deposits. Beijing: Science Press.

Uses data from many canyons including La Jolla and Scripps Canyons to discuss canyon currents, alternating currents, internal waves, and deposits.

Elberson, M. A. and K. R. Sowers (1997). "Isolation of an aceticlastic strain of Methanosarcina siciliae from marine canyon sediments and emendation of the species description for Methanosarcina siciliae." International Journal of Systematic Bacteriology 47(4): 1258-1261.

A newly described strain of the genus Methanosarcina was isolated from submarine canyon sediments and is shown by comparative sequence analyses of 16S ribosomal DNA and the gene encoding methyl coenzyme M reductase, mcr1, to be a strain of Methanosarcina siciliae. Morphological and physiological characteristics are described. In

contrast to the two previously described strains that grow exclusively on methanol, methylamines, and dimethylsulfide, M. siciliae C2J is also capable of growth on and methanogenesis from acetate. We propose that the species description for M. siciliae be amended to include aceticlastic strains.

Santangelo, Richard V. , Dario W. Diehl and Stephen B. Weisberg (1997). Spatial Characterization of Four Water Column Parameters on the Mainland Shelf of Southern California in July 1994. Westminster, California: Southern California Coastal Water Research Project Authority.

A 261-site water quality survey of the southern California coastal shelf was conducted between July 12 and July 18, 1994. A localized upwelling event (19 m site) over La Jolla Canyon showed surface parameters with low temperature, high salinity (>34.00 psu), and low oxygen. Surface salinity was relatively homogeneous throughout the Southern California Bight; the area with the highest salinity (0.38 psu higher than surrounding sites) was identified at the head of La Jolla Canyon. Salinity at this location was typical of water from 120 to 150 m. These measurements suggest that the source is deep water coming up the canyon and surfacing instead of intermediate water, as indicated by the anomalous area south of Point Loma. Canyons and headlands are known foci of almost continual upwelling patterns.

Jaffe, Jules S. (1996). Acousto-optic studies of La Jolla Canyon. IN: California Sea Grant. Biennial Report Of Completed Projects 1992-94. Report R-CSGCP (University of California (System). Sea Grant College Program) no. 040. La Jolla, California: California Sea Grant College System, University of California.

A basic goal of the experiments was to track individual zooplankters in the water column for periods as long as possible. Over a 2-day period, the Sproul was deployed over the La Jolla Canyon, and the ROV was used in the water for periods as long as 8 hours. The system was used in several different ways. In one case the system was kept at a fixed depth and was used to monitor the rate of flux of animals that were migrating vertically.

Martin, Joel W., Eric W. Vetter and Cora E. Cash-Clark (1996). "Description, external morphology, and natural history observations of Nebalia hessleri, new species (Phyllocarida: Leptostraca), from southern California, with a key to the extant families and genera of the Leptostraca." Journal of Crustacean Biology 16(2): 347-372.

A new and relatively large species of leptostracan crustacean, Nebalia hessleri, is described from enriched sediments and detrital mats off southern California. The new species is characterized by its size, possession of "normal" (versus lobed) eyes,

rectangular and unpaired subrostral keel, acute dentition of the posterior pleonite borders, and caudal furca approximately twice the length of the telson Clark's Nebalia pugettensis (Clark, 1932) is herein declared a nomen nudum. The new species differs from specimens at Friday Harbor, Puget Sound, Washington, in the form of the epimeron of the fourth pleonite, the dentition along the posterior border of the fifth through seventh pleonites, the relative length of the telson and caudal furca, and size. Coloration may also serve to distinguish N. hessleri from other species if egg-bearing females are available; eggs of N. hessleri are cream or gold colored. The new species differs from a currently unnamed sympatric species that occurs in adjacent sand flats primarily in the morphology of the first antenna, which is greatly reduced in the sand-flat species, and the eye, which has unique dorsal and ventral corneal protrusions in the sand-flat species. Selected aspects of the external morphology of the new species are illustrated via scanning electron microscopy, highlighting a previously unappreciated diversity of spines and setal types. Based on these photographs, some limbs are suggested as having sensory functions. Selected features of the Friday Harbor specimens also are illustrated via SEM. Limited notes on feeding behavior and oxygen level tolerances are provided, based on preliminary laboratory observations. Finally, we include a morphology-based key to identification of the currently recognized families and genera of the Leptostraca.

Vetter, Eric W. (1996). "Life-history patterns of two Southern California Nebalia species (Crustacea: Leptostraca): the failure of form to predict function." Marine Biology 127(1): 131-141.

Laboratory and field studies on Nebalia hessleri and N. daytoni showed that although morphologically similar, the habitats, behavior, and natural history of these two species are surprisingly different. In laboratory experiments, each species avoided the other's habitat (sand and mats of macrophyte detritus), and in the field, transplanted individuals failed to survive in the other species' habitat. N. hessleri, which inhabits subtidal mats of macrophyte detritus (the Scripps Canyon detrital mat), survived and reproduced well in the laboratory, was iteroparous, and a large percentage of adults were male. This species occurred at very high densities in the field, and ate essentially everything offered in the laboratory, with a diet in the field consisting largely of plant detritus and carrion. The other species, N. daytoni, differed in nearly every way, it inhabited organically impoverished sands (the sand plain off SIO Pier), survived poorly in the laboratory, was apparently semelparous, and a small percentage of the adult population was male.

Hlebica, Joe (1995). "Submarine smorgasbord, feasting in the food chain." Scripps Institution of Oceanography Explorations 2(1): 18-25.

Summarizes work of Dr Eric W. Vetter in studying the productivity of the Scripps Canyon debris

Vetter, Eric W. (1995). "Detritus-based patches of high secondary production in the nearshore benthos." Marine Ecology Progress Series 120(1-3): 251-262.

Topographical features like depressions and submarine canyons accumulate organic debris that fuel patches of intense secondary production. A submarine canyon system off the coast of La Jolla harbors an assemblage of leptostracan and amphipod crustaceans whose local density and secondary production greatly exceed those of any natural system yet reported. These crustaceans utilize large accumulations of macrophyte detritus as both habitat and food, and are preyed on by numerous species of fishes. Bottom topographies acting as detritus traps are relatively common along many coasts and provide an important mechanism to channel marine macrophyte production into higher trophic levels.

Vetter, Eric W. (1995). Southern California Nebalia: ecology, production, natural history and systematics of two subtidal species. Ph.D. dissertation, Scripps Institution of Oceanography, University Of California, San Diego.

This dissertation examines the factors that limit the distribution and abundance of Nebalia daytoni and N. hessleri, two previously undescribed species of leptostracan crustaceans. N. daytoni is found inhabiting the sand plain off La Jolla from depths of 8 to 35 meters. N. hessleri inhabits large accumulations of kelp and surfgrass detritus within the La Jolla and Scripps Canyons. The submarine canyon detritus mats provide food and refuge for a dense (up to 3,500,000 individuals per square meter) assemblage of amphipods and leptostracans. This assemblage has both the greatest density, and highest secondary production of any macrofaunal community studied. Large, multi-species aggregations of fishes prey on the detritus mat invertebrates year round, with physical and biological disturbances making the invertebrates more vulnerable. Winter storms cause a physical disturbance which greatly reduces the extent and thickness of the mat by washing much detritus down the canyon. This concentrates the invertebrates and reduces the quality of their refuge. During the summer, calm conditions allow bacterial mats to grow over the detritus, covering as much as 75% of the total area. The mat invertebrates avoid the areas affected by the bacteria, concentrating in the bacterial free zones and becoming more vulnerable to predation. The size and condition of the detritus mat determines the carrying capacity of the habitat. Fishes are the proximate agents causing reductions of the mat invertebrate populations when disturbance reduces the carrying capacity of the habitat. Though morphologically similar, the habitats, behavior and natural history of these two species was surprisingly different. The Nebalia sp. inhabiting subtidal mats of macrophyte detritus, survived and reproduced well in the lab, is iteroparous, and a large percentage of adults were male. They also occurred at very high densities, with a diet consisting largely of macrophyte detritus and carrion. The other species, N. daytoni, differed in nearly every way, being semelparous, inhabiting organically impoverished sands at relatively low density, and with males amounting to a

very small fraction of the adult population. N. daytoni also survived poorly in the lab and was not a carrion feeder.

Anon. (1994). "Daunting densities in undersea scum." Science News 146(21): 334. Nov 19 1994.

Brief news item about research of Eric W Vetter reporting three million crustaceans living in each square meter of decaying surf grass in Scripps Canyon

Nelson, C. Hans, E.B. Karabanov, S. Colman, C. Escutia and J. H. Jr Barber (1994). "High sedimentation rates in modern ponded turbidite basins compared to low-rates in drained basins." Abstracts with Programs, Geological Society of America 26(7): 70 (abstract).

Vetter, Eric W. (1994). "Hotspots of benthic production." Nature 372(6501): 47.

Topographical features that accumulate organic debris, such as submarine canyons, are common along many coasts and can support hotspots of secondary production. The floor of La Jolla canyon is covered by a persistent mat of surfgrass and kelp detritus from a depth of 15 m to at least 300 m. The detritus is inhabited by a dense assemblage of amphipod Orchomene limodes, Aoroides spinosus, and leptostracan Nebalia spp. crustaceans which at times achieve densities of more than 3 million individuals and biomass exceeding 1 kg (dry weight) per square meter. In monthly samples collected from March 1992 to March 1993, leptostracan density averaged 690,000 per square meter and amphipods 780,000 per square meter. The combined maximum density of these animals was 3,240,000 per square meter, an order of magnitude greater than any natural macrofaunal assemblage reported in the literature. The amphipods are generally distributed within the top 10-20 cm of the detritus mat and the leptostracans are most abundant 5-25 cm into the detritus; leptostracans are the preferred prey of the mat-associated fishes. Fish are the tertiary predators in this system and functionally shunt the detritus-based saprotrophic production into the classic biotrophic coastal food web. These localized productivity hotspots may, in aggregate, be an important energy supply for fish production along some coasts. Systems such as this provide an important mechanism to channel marine macrophyte production into higher trophic levels through a saprotrophic food web.

Rindell, Anders K. (1993). Faults and associated landslides on the Torrey Pines mesa, an expression of the active Rose Canyon fault zone, La Jolla, California. Geological Society of America, Abstracts with Programs. 89th annual meeting of the Cordilleran Section and

the 46th annual meeting of the Rocky Mountain Section of the Geological Society of America (GSA), Reno NV. pp. 139.

The Rose Canyon fault zone (RCFZ), San Diego's active NW striking right-lateral wrench, bends to the left at La Jolla, creating a poorly understood zone of transpression. North of La Jolla, continuing investigations along seacliffs and road-cuts have exposed a number of en echelon, NE striking antithetic faults previously interpreted as either E-W striking faults, landslides, and/or Eocene soft-sediment deformations. However, thrust faulting and left-lateral movement, in addition to antithetic strikes, indicates that at least one of these, the Marine Fisheries fault, is associated with the RCFZ. A graben formed by a left-step along this fault has led to land subsidence and engineering problems for the National Marine Fisheries building. In addition, progressive seacliff retreat here and at other locations is partly controlled by fault associated fractures. A cliff-face exposure of the Salk fault reveals diverging fault splays flattening to the near horizontal with movement occurring along bedding planes within the sedimentary section, creating the appearance of landsliding. Classic flower structures have also been found up to 5 km inland, along NE strikes to the shoreline exposures of the Salk and Scripps faults. Faults traces are generally obscured by urbanization and numerous ancient and/or presently active coherent landslides. Although these faults are classified as only potentially active, timing and risk of seismic movement are not well constrained. In addition, record rainfalls in San Diego County have dramatically increased landsliding potential. A well exposed dike, dated at 11 Ma (older than the Pliocene age of the RCFZ), is exposed from the seacliffs offshore towards the RCFZ. It has a significant magnetic anomaly ranging up to 450 gammas and appears to be offset by the Marine Fisheries and Scripps faults. Measuring offsets of this and other reported and suspected offshore dikes may better define total offset from both the RCFZ and antithetic faulting.

Vetter, Eric W. (1993). "Extraordinarily high secondary productivity fueled by kelp and surfgrass detritus at the head of the La Jolla submarine canyon." American Zoologist 33(5): 17A.

Lee, John H. (1992). Divers Feared Dead After Pushing Limit for Depth. Los Angeles Times San Diego County Edition: Metro Section Part B, Page 1, Column 2.

...Scuba enthusiasts Scott Lansinger and Ed Brennick set out to dive deeper than either had ever been. They set their goal at 250 feet, which amateur and expert divers say is about 100 feet beyond reason. "I heard their plan," said Lansinger's fiancee, Tisa Ozar, "and thought it was insane." Ozar, 21, is a certified diver. The two men were reported missing Tuesday night in a deep sea canyon off La Jolla Shores. After three searches, lifeguards told relatives and friends Wednesday afternoon that there was little hope the pair would be found alive. Shortly after Lansinger, 31, of Escondido and Brennick, 30, of Poway were reported missing, their car was found in the Shores parking

lot. Inside were two full dive tanks that the pair usually kept on hand for a second session of diving. They were last seen about noon Tuesday, when they set out to beat their personal bests. Just last weekend, Ozar said, the two had come back from the deepest dive of their lives -- 197 feet for Scott, 200 for Ed. "Scott and Ed would just encourage each other to go to the limit," Ozar said. "In anything they did, they were totally competitive." Friends for years, Lansinger and Brennick were both certified as dive masters from the same school. Brennick, a carpenter, had about six years' diving experience; Lansinger, a computer repairman for IBM, had 12. During last weekend's dive, friends and relatives said, the two men experienced nitrogen narcosis.... "Two hundred fifty feet is like suicide," said Werner Kurn, a master dive instructor and president of Ocean Enterprises, the diving school where the missing men were certified. "If I hear anyone talking like that, I stop the conversation right there. It's like saying, 'I'm going to play Russian roulette. I'm loading the gun . . . ' ". Ozar said she asked Lansinger on Monday if he experienced the "high" of nitrogen narcosis on his last dive. " 'Yeah, big time,' " Ozar quoted her fiance as saying. "Don't you think it's stupid to go farther?" she admonished before he set out on the last dive. "He laughed." "It's cool," was Lansinger's reply. For Brennick, diving was a natural fix for an adrenaline craving felt since childhood. He was particularly excited about being certified as a dive master just this month, and his enthusiasm for diving seemed heightened in recent days, said his brother, Kevin Brennick. Also an avid rock climber and parachutist, Brennick knew how to take risks, his brother said: "He didn't like to sit home and watch TV." But he also knew about people pushing themselves too far, his brother said. Ed Brennick had recently been on an extensive boat trip to Mexico. A rescue during that trip stuck with him, Kevin Brennick said. "Ed was on a team looking for a lost diver," Kevin Brennick said. "He was the one who found the guy's body wedged in a rock at 160 feet. . . .That really hit close to home. Ed seemed a lot mellower, a lot more cautious after that." Kevin Brennick said his brother's fiancee, Patricia Silva, is eight months pregnant, and the family had hoped that the baby would tone down his acts of daring. Late Wednesday as the families of the two men clung to slim hopes of their survival, Kevin Brennick described a familiar feeling of dread. "We have always worried about him," he said. "And it was always nice to get that phone call from him saying everything's OK." Lifeguard Lt. Brant Bass said all Coast Guard and city lifeguard teams in the area were told of the disappearance and will continue to keep on the lookout, though formal rescue efforts have been halted.

Rindell, Anders K. (1992). Offset of a submarine dike as a 3-D strain marker for determining horizontal and vertical motion of the Rose Canyon fault zone and associated positive flower structures, La Jolla, California. Geological Society of America, Cordilleran Section, 88th annual meeting, Eugene, Oregon, Geological Society of America, Cordilleran Section. pp. 78 (abstract).

Abbott, Patrick L. and William J. Elliott (1991). Field trip log; Geologic hazards in San Diego. IN: Environmental perils; San Diego region. P. L. Abbott and W. J. Elliott. San Diego: San Diego Association of Geologists: 235-250.

Lohmar, John M. and Scott R. Morgan (1991). "Eustatic and tectonic controls on depositional sequences in the Eocene La Jolla Group, San Diego, California." Abstracts with Programs, Geological Society of America 23(2): 74.

Rindell, Anders K. (1991). An investigation of Scripps Submarine Canyon: its geology, sedimentary regime, and bubbling gases. Masters Thesis, San Diego State University.

Snyder, R.A. and Mark D. Ohman (1991). "Description of a new species of Strombidinopsidae (Ciliophora: Choreotrichida) from coastal waters of southern California, U.S.A." Transactions of the American Microscopical Society 110(3): 237-243.

The planktonic ciliate protist Strombidinopsis cheshiri n. sp. is described from Protargol-stained preparations of cultured cells. The specimens reacted unsatisfactorily to commonly used fixatives; 87% disintegrated in Bouin's fluid, leaving only oral polykinetids. Cell shape changed from spherical in recently divided cells to long and tapered in pre-division cells. The range of cell size was 34-110 .mu.m (l) .times. 32-60 .mu.m (w). Fourteen to sixteen external oral polykinetids had oral membranelle cilia 14-16 .mu.m long. Four inner oral polykinetids were found within the infundibulum. Twelve to fifteen somatic kineties extended for the entire length of the cell, with 18-32 dikenitids per kinety. Both kinetosomes of each kinetid bore cilia 4 .mu.m long. Incomplete kineties were common. Two roughly ovoid macronuclei and one micronucleus were found per cell. S. cheshiri was algivorous in laboratory culture.

Stewart, Joan G. (1991). Marine algae and seagrasses of San Diego County. La Jolla: California Sea Grant College.

LA JOLLA CANYON: The narrow sloping terraces of the head of La Jolla Canyon are often densely covered with clumps of Acrosorium uncinatum,interspersed with Stenogramma interrupta, Sarcodiotheca furcata, and Sarcodiotheca gaudichaudii. Seasonally, Dictyopteris undulata, Agarum fimbriatum, and scattered Desmarestia ligulata of all sizes are common. Mats of filamentous diatoms often appear as a brown film over large areas of fine-grained mud. The red fuzz that one observes on worm tubes, pieces of broken shells, or larger attached algae includes species of Polysiphonia, Ceramium, and Antithamnion. As noted below this is one of the few sites where large speciments of S. gaudichaudii can be found. Juvenile, occasionally larger, plants of Macrocystis have

been noted nearby but are not consistently present. Sargassum muticum also is occasionally present, not abundant. A population of Sarcodiotheca furcata has persisted for at least twenty years in 17-27 meters near the edge of the head of La Jolla Canyon where it is one of several large algae that form a unique assemblage of taxa. Intermittently Stenogramma interrupta, Sarcodiotheca gaudichaudii, Agarum fimbriatum, Acrosorium uncinatum, and Desmarestia ligulata occur, but little else grows here. This is the only source of Sarcodiotheca furcata known by the author along the San Diego County coast, perhaps in Southern California. This particular site is referred to locally as Sarcodiotheca Point. The population persisted, apparently unchanged in extent since first observed in 1958, until a storm in January 1988 left the area bare of vegetation. The area is between 18 and 23 meters with sand, small cobbles, and scattered shells overlying the shale bedrock. Stenogramma interrupta and large Sarcodiotheca gaudichaudii thalli were usually associated with S. furcata and seasonally Desmarestia ligulata was abundant. Cystocarpic plants of Stenogramma interrupta have been collected from January to June among thalli of S. furcata near the edge of La Jolla Canyon. Nonreproductive plants that resemble these cystocarpic thalli are so irregularly branched that they might, if collected separately, be treated as forms of Ozophora. The variability in this particular population may be partly related to the longevity of individual thalli. The site is beneath the depths of heavy surge, possibly allowing thalli to persist and grow over several years. It is also a sandy area, removed from rock outcroppings inhabited by fish or large invertebrate grazers. These very small thalli are found February through June with pale clear pink blades. These new thalli grow to one meter high by the end of summer, with ultimate dichotomies one centimeter wide. Simultaneously older blades to fifteen centimeters high are found that are thicker and usually eroded or torn, darker colored, and often fertile. If these were found apart from the new thalli, they would initially be considered a different species. From many of these old thalli, thin new blades, with the bright color and regualr dichotomous branching of the first-year growth, develop along old margins or apices. This is the only site where this species has been bound off San Diego County. Since a January storm in 1988 disturbed substrates, algal thalli of these larger species have not been found. SCRIPPS CANYON: The head of North Branch of Scripps Canyon at about 30-40 meters differs markedly in its algal flora. Below thirty meters, Maripelta rotata grows and is recognized by a vivid blue iridescent sheen to its thin, smooth, slippery-feeling circular blade developed singly on top of a stipe. M. rotata is a deep-water alga and is found either very deep under Pelagophycus porra blades outside Macrocystis beds or in the Canyon below 28 meters and at least as deep as sixty meters. In addition to M. rotata, one can see Ozophora, abundant Rhodymenia, several forms or species of Callophyllis, Dictyopteris, Schizymenia dawsonii, and large red blades that variously represent Halymenia, Gigartina exasperata, Polyneura or other species. These are conspicuous in North Branch of Scripps Canyon while typically absent or more rare in La Jolla Canyon. The sponges, rock surfaces and stalks of gorgornian are often bare of epiphytes. Characteristically, there is little Acrosorium (compared with the large clumps in La Jolla Canyon) and no S. furcata or S. interrupta. In shallow water, about twenty meters deep and north of the North Branch Canyon rim, a stable rocky bottom supports algal assemblages very similar to those on the Loma Sea Cliffs at the same depths.

Lohmar, John M. and S. R. Morgan (1990). "Sequence stratigraphy of Eocene shelf and slope deposits, San Diego Embayment, California." AAPG Bulletin (American Association of Petroleum Geologists) 74(5): 707-708.

Analysis of Eocene shelf and canyon deposits of the San Diego embayment illustrates the applicability of sequence stratigraphic principles in tectonically active regions. Formations of the La Jolla Group are separated by widely correlatable sequence boundaries produced by sea level fluctuations. Sequence boundaries chronostratigraphically define, in ascending order, the Delmar, Torrey, Ardath, Scripps, and Friars formations of the La Jolla Group, and the base of the overlying Poway Group. Contemporaneous tectonism produced regional subsidence, resulting in gradual innundation of the shelf, and rapid, fault-related subsidence accompanied by deposition of a localized sedimentary wedge in the Ardath. Consequently, the thickness and paleobathymetry of the Ardath wedge exceed that expected from regional subsidence, erosional accommodation, and eustatic rise alone. Due to shelfal subsidence, the Delmar, Torrey, and Ardath form a transgressive succession of marsh/intertidal, subtidal, and submarine canyon deposits bounded by sequence boundaries, expressed as erosional unconformities. Facies successions across these surfaces generally deepen upward, with basinward facies shifts restricted to the updip limit of these depositional systems. Although falling sea level initiates these sequences, subsidence limits exposure of the shelf and accompanying basinward shift of facies to a narrow band along the shoreline. In contrast, overlying units exhibit a regressive stacking pattern indicative of reduced subsidence and/or increased sedimentation. Facies successions across sequence boundaries between these units exhibit a more widespread basinward shift. The stratigraphy of the La Jolla Group illustrates that high-frequency sea level fluctuations produce depositional sequences that are fundamental chronostratigraphic units of basin fill on both active and stable margins.

Seymour, Richard J. (1990). Autosuspending turbidity flows. IN: The Sea: ideas and observations on progress in the study of the seas. Volume 9B: Ocean engineering science,. B. Le Mehaute and D. M. Hanes. New York: Wiley: 919-940.

Stacey, M.W. and A.J. Bowen (1990). "A comparison of an autosuspension criterion to field observations of five turbidity currents." Sedimentology 37(1): 1-5.

An autosuspension criterion that has been developed directly from the fluid dynamical equations, by taking into account the vertical structure of turbidity currents, is compared to field observations of five turbidity currents. It is found that the criterion is consistent with the motion of all 5 currents, which suggests that the criterion may, at least

under certain circumstances, be a reasonable guide in estimating the conditions necessary for a turbidity current to be self-sustaining.

Dayton, Paul K., Richard J. Seymour, P.E. Parnell and Mia J. Tegner (1989). "Unusual Marine Erosion in San Diego County from a Single Storm." Estuarine, Coastal and Shelf Science 29(2): 151-160.

Observations of wave-induced geological damage were made along the San Diego coastline to a depth of 25m, following the storm of 17-18 January, 1988. Massive damage to limestone reefs occurred, including the shearing of individual sections with in-water weights of over 20 tons at the remarkable depth of at least 22 m. Large sections of the walls of a submarine canyon were broken off at a depth exceeding 20 m. The drag and inertial forces from the waves in this storm are shown to be about twice those in the largest previous storms of the century, and it appears to be a 200 year event. In addition to the kelp mortality reported in Seymour et al., 1989, there was extensive mortality among encrusting algal and animal communities. The apparent age of the mature successional communities in the deeper sites supports the engineering estimates of the rarity of this event. The movement of cobbles and boulders at depths almost twice as great as the previously assumed limits on effective sediment transport may require coastal engineers to revise cross-shore transport models.

Garcia, Marcelo and Gary Parker. (1989). "Experiments on hydraulic jumps in turbidity currents near a canyon-fan transition." Science 245(4916): 393-396. July 28 1989.

The point at which a submarine canyon debouches on its associated abyssal fan is generally characterized by a drop in channel slope. Turbidity currents of the kind responsible for the genesis of the canyon and fan should display an internal hydraulic jump near the slope transition. No direct field observations of any such jump appear, however, to have been made. Experiments on the nature of the jump and the resulting sedimentary deposits indicate that the thickness of the deposits just downstream of the jump tends to increase as the ratio of bed shear velocity immediately behind the jump to particle fall velocity decreases.

Gorsline, D. S. (1989). Clast-contact conglomerates in submarine canyon fill: possible subaqueous sieve deposits. IN: Conglomerates in Basin Analysis, SEPM Pacific Section Publication 62. I. Colburn, Abbott, P. and Minch, J., (eds.): 99-112.

Loos, C.G. (1989). "Scripps trips pay off." Salt Water Sportsman, California Edition 50(3): F-H. March 1989 1989.

Author relates fishing experience in Scripps Canyon

Everts, Craig.H. and Robert F. Dill (1988). Sedimentation in submarine canyons, San Diego County, California, 1984-1987. US Army Corps of Engineers, Coastal Engineering Research Center, Waterways Experiment Station. Reference No. CSTWS 88-2. April 1988.

Three submarine canyons have an effect on the coast north of San Diego, California. Scripps and La Jolla Canyons extend almost to shore and permanently trap sand at the south end of the Oceanside Littoral Cell. They are also responsible for enhancing the local, long-term shoreline retreat rate as evidenced by the embayed shoreline adjacent to each. Carlsbad Submarine Canyon, in the central portion of the Oceanside Cell, extends shoreward across the Continental Shelf to a water depth of about 100 ft. Littoral sand is not carried to the canyon head at that depth. The effects of wave refraction over Carlsbad Canyon have resulted in a reduction in the local rate of shoreline retreat and produced a slight bulge in the nearby shoreline.

The first objective of the field investigation described in this report was to quantify the rate at which littoral sand was carried to and deposited in the shallow heads of Scripps and La Jolla Canyons between December 1984 and June 1987. The second objective was to establish, for the same period, the rate at which the deposited material was flushed down the axes of the canyons. Littoral sand, once it is flushed to deep water, is unrecoverable. The frequency, magnitude and duration of storms, the characteristics of the local longshore sediment transport regime, and the location and shape of the heads of the canyons control the entrapment rate, how much sand the canyon head can hold before it is flushed out, and the frequency of flushing.

Sand Entrapment Rate. Scripps Canyon has at least 6 shallow-water tributaries that trap sand. The most active four were investigated in this study. La Jolla Canyon has a single, but much larger, O.7-mi long, shallow-water head. Canyon heads filled when sand moved seaward from the littoral zone into nearcoast sediment depressions. Depressions are shallow, relatively steep, saucer-shaped region located above canyon gorges. Gorges are comprised of rock headwalls, rock sidewalls that in some places are vertical or even overhanging, and rocky, seaward-sloping floors.

Sand that had the same size distribution as sediments in the nearby littoral zone was deposited in the depressions. Very fine-grained sands, micas, and organic debris passed over the depressions and were deposited in the gorges. As the prograding deposits in the depressions of Scripps Canyon were funnelled into the narrow (10 to 200-ft wide) gorges,

they moved on top of the finer, lower-specific-gravity material. Relatively little passed over the sidewalls. In La Jolla Canyon about equal amounts of sand passed into the gorge over the rim of its wide headwall, and through several chute-like depressions or reentrants that pierce the headwall.

Sumner and South Branches are presently the most active tributaries of Scripps Canyon. The upper boundaries of their depressions are closest to shore and they intercepted more sand than tributaries that began in deeper water. Sumner and South Branches are located near the north end of the tributary system of Scripps Canyon and preferentially filled when longshore sediment transport was to the south. The north re-entrant of La Jolla Canyon was the most active part of that canyon, even though the gorge there is farther from shore than it is elsewhere.

In both canyons a much larger volume of littoral sand was initially deposited in the depressions than in the gorges. The ratio was about 20:1 in Sumner and South Branches.

Over 80 percent of the sand was transported seaward into the canyon heads between November and May during wave storms, probably more the result of storm-induced downwelling than transport in rip currents. Shore-normal transport was dominant. A relatively small quantity of sand entered the canyon heads parallel to shore. Only small amounts of littoral sand were carried into the depressions during the summer and autumn, but large quantities of mica and especially kelp and ,sea grass debris was deposited in the gorges at all times of year. Organic debris was transported by rip currents over the headwalls, and by longshore currents over the sidewalls.

An average of about 29,000 yd3/yr of littoral sand was deposited in the shallow heads of the canyons between December 1984 and June 1987. Only about 1,000 yd3/yr of that was trapped in La Jolla Canyon. In Scripps Canyon an average of about 22,000 yd3/yr was deposited in Sumner Branch; about 2,000 yd3/yr was deposited in South Branch. The long-term rate of littoral sand entrapment in or adjacent to Scripps and La Jolla Canyons appears to be approximately equal to the net longshore sediment transport rate at the south end of the Oceanside Littoral Cell.

Sand Flushing Rate. Once littoral sand passed over the upper edge of the depression it was carried downslope in small surface slumps and by wave-induced bottom oscillations coupled with gravity. In this way a critical slope of about 18 degrees was maintained at the seaward face of the prograding deposit. The normal load created by this deposit

increased greatly as its toe prograded onto the steeply-dipping deposit in the gorges of Sumner and South Branches. When the normal load exceeded the internal shear strength of the deposit a massive downslope movement of sediment occurred. The slumps and slides were also controlled, in part, by the decomposition of organic debris that reduced the strength of the deposit near the floor of the gorges. The heads of Scripps Canyon apparently reach a critical volume of sand at which time the deposit is susceptible to failure. In Sumner Branch the critical volume is about 50,000 yd3 while in South Branch it is about 5,000 yd3.

Flushing occurred when storms moved large quantities of sand onto the upper part of the depressions, thereby increasing the normal load. Sumner, South and Shepard Branches flushed on 13 December 1984. Sumner and South Branches filled and again flushed in early spring 1987, so their flushing frequency during the field investigation was O.4/yr. The flushing frequency of other Scripps Canyon tributary valleys is estimated to be O.025+/yr.

Flushing occurs most often in gorges with steeply-sloping floors that fill rapidly because they head close to shore. Wave loading may be a factor in reducing the strength of the deposit during storms.

Kernan, Michael Rowan (1988). The Chemistry Of Some Marine Sponges. Ph.D dissertation, University Of California, San Diego.

The chemistry of some marine sponges is discussed in this thesis. The sponge Halichondria sp. contains halichondramide, which is a highly effective antifungal and cytotoxic agent, and a potent inhibitor of feeding by the fish Thallasoma lutescens. Five related constituents were isolated from a large collection of Halichondria. The dorid nudibranch Hexabranchus sanguineus includes the sponge Halichondria sp. in its diet, and converts halichondramide into two related macrolides and concentrates these macrolides in their dorsal mantle, digestive gland, and egg masses. A sponge of the family Halichondriidae collected from Scripps Canyon, contained halisulfate 1, a novel sulfated hydroquinone that showed in vitro antiviral and anti-inflammatory activity, and five new sulfated furans, halisulfates 2-6, that were related to suvanine. Some specimens of Luffariella variabilis contained the sesterterpenes luffariellin A and luffariellin B, which are potent inhibitors of the enzyme phospholipase A2 (PLA2) and effective anti-inflammatory agents. Certain specimens of the nudibranch Chromodoris funerea contained the butenolides luffariellin C and luffariellin D. A Luffariella sp. sponge contained luffariellolide and luffolide, both of which are anti-inflammatory and are inhibitors of PLA2. Oxidation of the furanoid metabolites of the sponge Dysidea sp. with singlet oxygen gave a suite of products that was identical to those isolated from some specimens of the nudibranch

Chromodoris funerea that were feeding on the sponge. Treatment of a 3-substituted furan with singlet oxygen in the presence of a hindered amine base gave high yields of 3-alkyl-4-hydroxybutenolides. The 3-alkyl-4-hydroxybutenolides had in vivo anti-inflammatory activity. The structure activity relationships within this series of metabolites and the Luffariella metabolites, and the mechanism of inhibition of bee venom PLA2, are discussed in the final chapter.

Shapiro, Russell S. (1988). Sedimentary and environmental changes in the south branch of the Scripps Submarine Canyon. 1988 San Diego Science Fair. 1988.

1988 Isaacs Scholarship report. High school student paper.

Swift, E., J. Van Keuren, H. P. Batchelder, C. R. Booth and C. P. Li (1988). A moored instrument to measure stimulated and natural oceanic bioluminescence. Proceedings SPIE. vol. 925. Ocean Optics IX, Orlando, FL. pp. 76-86.

An instrument has been developed to measure stimulated and natural bioluminescence for periods of up to four months at an oceanic mooring. This article describes the instrument and the nature of the bioluminescence it is designed to measure. Results from a test mooring in Scripps Canyon are given.

Webb, D.A. (1988). A structural interpretation of Scripps Submarine Canyon. Advances in Underwater Science - 1988. Proceedings of the American Academy of Underwater Sciences, 8th Annual Scientific Diving Symposium, La Jolla, CA, American Academy of Underwater Sciences. pp. 213-220.

Everts, Craig H., Robert F. Dill, Anthony Jones, Thomas Lorensen, Kevin Kelly and Richard B. Wilkins (1987). Littoral Sand Losses to Scripps Submarine Canyon. Coastal Sediments '87, Proceedings of a Specialty Conference on Advances in Understanding of Coastal Sediment Processes, Moffatt & Nichol, Engineers, Long Beach, CA, USA

Published by ASCE, New York, NY, USA. pp. 12-14 (p 1549-1562?).

An investigation of Summer Branch, the most active of the four heads of Scripps Canyon, showed 42,000 cubic meters of littoral sand was deposited in it between 13 December 1984 and 7 November 1986. This was about one-fifth the average annual loss rate Chamberlain (1964) estimated for the period between 1984 and 1960. The large difference may be the result of variations in the net annual longshore sediment transport rate. Northerly transport, which was frequent between December 1984 and November

1986, decreases sand availability in the littoral zone adjacent to the canyon head. Unbalanced offshore-onshore sediment particle oscillations in the shallower parts of the depression, and failure of the sediment surface as evidenced by frequent and numerous small slumps, and one larger mass movement, were the primary mechanisms of downslope movement.

Judy, Thomas C. (1987). Reconnaissance Geology of Holocene Lagoonal Deposits in the La Jolla Submarine Canyon and Their Relationship to the Rose Canyon Fault, Department of Geological Sciences, San Diego State University.

This study is a part of the investigations of Dr. Robert F. Dill and others to study the La Jolla Submarine Canyon for indications of tectonic activity and sea level fluctuations during the Holocene. Reconnaissance geology of Holocene lagoonal deposits in the head of the La Jolla Submarine Canyon and their relationship to the Rose Canyon fault were conducted underwater using S.C.U.B.A.

La Jolla Submarine Canyon cuts across the continental shelf. Exposed in its wall are uniform lagoonal deposits deposited during the Holocene rise in sea level. Because lagoonal sediments are deposited in horizontal beds they present a datum for measuring tectonic movement occurring after their deposition, and a means of placing an age of these movements over the past 10,000 years before present. In San Diego county the major fault system offsetting coastal development projects by man is the Rose Canyon fault. The location of what are normally flat lying lagoonal clays exposed in the head wall of La Jolla Submarine Canyon across the seaward projection of the Rose Canyon fault, provided an excellent opportunity to determine if Holocene movement had displaced the lagoonal sequence.

The Rose Canyon fault parallels the San Andreas fault and other major faults of the California Continental borderland, and is one of a complex of en echelon faults that mark the boundary between the East Pacific and North American plates. On land Holocene activity along the known trace of the Rose Canyon fault has not been conclusively documented. This paper presents data and documentation on regional geology, geomorphology, age, structure, and seismic profiles of sediments in the head of La Jolla Submarine Canyon in order to determine whether activity has occurred along the Rose Canyon fault during the Holocene time. Holocene activity of the Rose Canyon fault has been an issue of debate for a number of years. The problem has been to find good undisturbed outcrops of Holocene sediment that show displacement by movement along the Rose Canyon fault. Through most of the trace of the Rose Canyon fault Holocene sediment is blanketed by Quaternary alluvium or in many cases has been developed by man. Studies to determine whether Holocene activity of the Rose Canyon fault has

occurred are important for assessing the seismic risk hazards in the San Diego area. As more refined data on the geology of San Diego county becomes available there is more evidence to support recent activity along faults in San Diego which were previously interpreted inactive. Recently geologist have found displacements in the late Pleistocene Linda Vista formation, and times of latest displacement are only provided by undisturbed Holocene alluvium. Although subaerial topographic features, such as sag pounds, and displaced geomorphic features, commonly associated with Holocene faulting have not yet been documented along the Rose Canyon fault evidence suggesting Holocene activity of the fault is present at the head of La Jolla Submarine Canyon.

Kennedy, Michael P. and H. Gary Greene (1987). "Structural formation of the La Jolla - Scripps submarine canyon system." Eos, Transactions, American Geophysical Union 68(44): 1316 (abstract).

Shapiro, Russell S. (1987). Sediment influence along La Jolla Submarine Canyon. 1987 San Diego Science Fair.

high school student paper

Stow, Douglas A. and Howard H. Chang (1987). "Coarse sediment delivery by coastal streams to the Oceanside littoral cell, California." Shore & Beach 55(1): 30-40.

Brownlee, Shannon. (1986). "Explorers of dark frontiers - submarine, Deep Rover, finds new species." Discover: 60-. February 1986.

FULL TEXT EXCERPT: An important thing to remember before diving in a small submarine: once you're inside, there's no getting out. This thought crosses my mind only after I'm sealed in the sphere of Deep Rover, a Volkswagen-sized submersible that's sinking swiftly in the ocean off La Jolla, Calif. The sub hits the sandy bottom 70 feet down with a jolt. In my nervousness, I forgot to use its propellers to slow its descent. Scuba divers hover anxiously around Deep Rover, like pilot fish about a shark. They peer inside; their underwater cameras flash. This must be how my goldfish feels. One diver makes a circle with thumb and forefinger and raises his eyebrows. O.K.? Fine, except that you guys are staring at me. I give the thumbs-up sign and they withdraw. The world becomes serene. Water moving past the sphere makes no sound; no color exists but blue. Finally remembering the propellers, I use them to maneuver the sub off the bottom, and it glides forward with surprising grace. I can make it spin on its axis, or execute sweeping curves, or tip to one side; the sub rises and stops, then falls again; it hangs for a few seconds four feet above the ocean floor. We swoop, the sub and I, we twist and gambol over the sand,

sometimes scraping the bottom clumsily and stirring up a cloud of silt. The call to ascend comes too soon, after an hour, but I reach obediently for an overhead valve to fill the ballast chambers with air. As I rise, the surface shimmers and undulates like spilled quicksilver, until it's rent by the sub bursting through. Divers splash noisily with their flippers as they guide me back to the mother ship. They hook a winch to a ring at the top of the sphere, clanging metal against metal, and the sub is hoisted on deck, where its hemispheres are unbuckled and opened by means of a hinge on the top. I squeeze out, a rumpled Venus emerging from her scallop shell. ... Our two-day cruise off La Jolla isn't quite so scientific. WhileEarle, a biologist, will collect specimens in collaboration with the Hubbs Marine Research Institute, the cruise is also intended to test the submersible at its maximum depth, and to give it "exposure." A TV crew is there, as well as assorted distinguished onlookers, like astronaut Kathryn Sullivan. There's a restaurateur who has won a dive in the sub at an auction, and a bunch of photographers. Tomorrow the ship will move farther offshore, where three people will each take Deep Rover down to 3,000 feet.... The lucky three are Earle, Graham Hawkes, Deep Rover's co-designer, and Phil Nuytten, president of Can- Dive Services, Ltd., which owns the sub and is Canada's largest provider of diving services to salvage operators and offshore oil rigs. ... The next morning at dawn the Egabrag's diesel engines spew blackexhaust as the vessel heads toward San Clemente Island, 60 miles out to sea....

Darigo, Nancy J. and Robert H. Osborne (1986). Quaternary stratigraphy and sedimentation of the inner continental shelf, San Diego County, California. IN: Shelf sands and sandstones. Memoirs of the Canadian Society of Petroleum Geologists. R. J. Knight and J. R.]McLean. Calgary, CA: Canadian Society of Petroleum Geologists. 11: 73-98.

Guilcher, A. (1986). "(Francis P. Shepard, 1897-1985, father of marine geomorphology)." Annales de Geographie 527: 87-98.

Francis P. Shepard (1897-1985), unanimously recognized as the father of marine geology, spent his life at Scripps Institution, La Jolla, California. Along with essential contributions in coastal geomorphology, and in sedimentology which he always associated with the description and explanation of shore features, he created submarine geomorphology. He is principally known for his numerous papers on submarine canyons.

Jenden, P. D. and I. R. Kaplan (1986). "Comparison of microbial gases from the Middle America Trench and Scripps Submarine Canyon: implications for the origin of natural gas." Applied Geochemistry 1(6): 631-646.

Chemical and isotopic compositions have been determined for 62 microbial gases from Tertiary hemipelagic sediments in the Middle America Trench off Guatemala and

from decaying kelp and surf grass accumulating in the Scripps Submarine Canyon off S California. The gases from the Middle America Trench are generated primarily by CO"SUB 2" reduction and have CH"SUB 4" delta "SUP 13"C values ranging -84 to -39per mille, CH"SUB 4" delta D values of -208 to -145per mille and an average carbon isotope fractionation between CO"SUB 2" and CH"SUB 4" of 70 + or - 10per mille. Gases from Scripps Submarine Canyon are generated mainly by acetate dissimilation and have CH"SUB 4" delta "SUP 13"C values ranging -63 to -43per mille and CH"SUB 4" delta D values of -331 to -280per mille. Results of this study suggest that unusually negative CH"SUB 4" delta D values or unusually positive CO"SUB 2" delta "SUP 13"C values may help to distinguish microbial gases with heavy methane delta "SUP 13"C values from thermogenic gases with low C"SUB 2"+ concentrations.

Molinski, Tadeusz F. and D. John Faulkner (1986). "Aromatic Norditerpenes from the Nudibranch Chromodoris macfarlandi." Journal; of Organic Chemistry 51(13): 2601-2603.

Dorid nudibranchs are shell-less marine molluscs that are believed to have acquired a chemical defense against predation that compensates for the loss of the shell. Members of the genus Chromodoris feed on sponges, from which they obtain their defensive chemicals. Twenty-two specimens of Chromodoris macfarlandi were collected by hand at a depth of approximately thirty meters in Scripps Canyon. Two aromatic norditerpenes, macfarlandin A and macfarlandin B, were isolated from Chromodoris macfarlandi. The macfarlandins 1 and 2 are closely related to the diterpene aplysulphurin, a metabolite of the sponge Aplysilla sulphurea.

Molinski, Tadeusz F., D. John Faulkner, He Cun-Heng, Gregory D. Van Duyne and Jon Clardy (1986). "Three New Rearranged Spongian Diterpenes From Chromodoris macfarlandi: Reappraisal Of the Structures Of Dendrillolides A and B." Journal of Organic Chemistry 51(24): 4564-4567.

Chromodoris macfarlandi collected at Scripps Canyon was found to contain three new diterpene acetates. The structure of macfarlandin C was determined by a single-crystal X-ray diffraction analysis. The structures of macfarlandin D and macfarlandin E were elucidated from spectral data. Comparison of the spectral data of macfarlandin D with those of dendrillolide A indicates that the proposed structure for the latter compound is incorrect.

Seymour, Richard J. (1986). "Nearshore auto-suspending turbidity flows." Ocean Engineering 13(5): 435-447.

A class of turbidity flows is investigated in which sediment is entrained sufficient to balance losses and an equilibrium flow is sustained. The analytical models for predicting

equilibrium flow configurations are surveyed. These are found to differ by two orders of magnitude in the required flow speeds. Five field observations of self-sustaining turbidity flows are investigated as a test for the analytical models. The model of Bagnold (1962) is found to have skill in predicting all of the field observations. The significance of these flows to the reliability of pipelines, cables and other engineering structures on continental shelves is considered. Circumstantial evidence is presented that suggests that these flows may be a mechanism for offshore flows of sand from beaches during major storms.

Bachman, Steven B. and Stephan A. Graham (1985). La Jolla Fan, Pacific Ocean. IN: Submarine fans and related turbidite systems. Frontiers in sedimentary geology. A. H. Bouma, W. R. Normark and N. E. Barnes. NY: Springer-Verlag: 65-69.

Fukushima, Y., G. Parker and H. M. Pantin (1985). "Prediction of ignitive turbidity currents in Scripps Submarine Canyon." Marine Geology 67(1-2): 55-81.

Swift, highly erosive continuous turbidity currents are known to be triggered in Scripps Canyon during storms. A relatively modest agitation due to edge waves can generate currents at least as swift as 1.9 meters per second. These constitute a major mechanism by which sand submarine canyons are eroded, and by which sand is delivered to the abyssal plain. Herein two models of steady, spatially developing turbidity currents are developed and applied to Scripps Canyon. Fairly specific predictions are obtained for the onset of ignitive acceleration, and for the downstream development of the turbidity currents. The results are in general agreement with available measurements in the same canyon. It is speculated that ignitive turbidity currents constitute a major mechanism by which sand submarine canyons are eroded, and by which sand is delivered to the abyssal plain.

Meador, J. P. and T. M. C. Present (1985). "Orchomene limodes, new species, a scavenging amphipod from Scripps Canyon, California: Species description and analysis of morphological variation." Journal Of Crustacean Biology 5(3): 523-538.

Orchomene limodes , new species (Amphipoda: Lysianassidae), recently discovered in Scripps Canyon, California, is described and compared to other species within this genus. Intraspecific analysis of morphological variation was performed in order to determine which characters would be appropriate for the description. Thirty-five potentially diagnostic characters were grouped into three types: qualitative, meristic, and morphometric, and analyzed for variation between individuals. The characters found invariant or slightly variable in this study were then used in the diagnosis of the species description.

Parker, G., H.M. Pantin and Y. Fukushima (1985). Self-accelerating turbidity currents. EUROMECH 192, Transport of Suspended Solids in Open Channels, Colloquium, Munich, Germany. pp. D9-1 - D9-7.

Turbidity currents are sediment laden underflows that occur in the ocean and lakes and are important mechanisms for the transport of littoral drift to deeper waters and can scour canyons. Considers self-accelerating turbidity currents for the case of a steady continuous current developing in the downstream direction. The three equation model may be extended to a four equation scheme with consideration of the dynamics of turbulence. Predictions are made for Scripps Canyon from models of turbidity currents known to occur there.

Kuhn, Gerald G. and Francis P. Shepard (1984). Sea Cliffs, Beaches, and Coastal Valleys of San Diego County. Berkeley, CA: University of California Press.

Brief discussion on "Submarine Canyons off La Jolla" on pages 128-131.

Nealson, Kenneth H., A. C. Arneson and A. Bratkovich (1984). "Preliminary results from studies of nocturnal bioluminescence with subsurface moored photometers." Marine Biology 83(2): 185-192.

Spatial and temporal patterns of bioluminescent flashes were recorded from fall 1982 through Spring 1983 by photometers moored offshore in Scripps Canyon. From depths between 8 and 90 m, real-time data were transmitted by cable to a laboratory on land approximately one mile (1.7 km) away. In addition, temperature, depth and current velocity and direction were monitored either in real time by direct coupling to a laboratory-based system, or by internal data storage systems that were retrieved at regular intervals and subsequently analyzed. The field station is largely uncoupled from wave action effects usually associated with luminescence measurements made from ships. Bioluminescent activity varied greatly both during a single night and between different nights. Vertical profiling of the water column between 8 and 90 m showed evidence of vertical migration, patchiness of distribution and large-scale spatial differences in total bioluminescent activity. Currents had a major impact on patterns of bioluminescent activity; however sometimes high levels of luminescence were recorded in complete absence of currents. Diel cycles, organism patchiness, the level of downwelling ambient light, and currents appeared to interact in controlling the levels and patterns of bioluminescence.

Snyderman, Marty. (1984). "Night diving - La Jolla submarine canyon." Skin Diver 33(7): 40-44. July 1984.

Describes the night diving experience and sea life in La Jolla Canyon.

Sowers, KR, SF Baron and JG Ferry (1984). "Methanosarcina acetivorans sp. nov., an acetotrophic methane-producing bacterium isolated from marine sediments (from the Sumner branch of Scripps Canyon located near La Jolla, California)." Applied and environmental microbiology 47(5): 971-978.

A new acetotrophic marine methane-producing bacterium that was isolated from the methane-evolving sediments of a marine canyon is described. Exponential phase cultures grown with sodium acetate contained irregularly shaped cocci that aggregated in the early stationary phase and finally differentiated into communal cysts that released individual cocci when ruptured or transferred to fresh medium. The irregularly shaped cocci (1.9 plus or minus 0.2 mm in diameter) were gram negative and occurred singly or in pairs. Cells were nonmotile, but possessed a single fimbria-like structure. Micrographs of thin sections showed a monolayered cell wall approximately 10 nm thick that consisted of protein subunits. The cells in aggregates were separated by visible septation. The communal cysts contained several single cocci encased in a common envelope. An amorphous form of the communal cysts that had incomplete septation and internal membrane-like vesicles was also present in late exponential phase cultures. The DNA base composition was 41 plus or minus 1% guanine plus cytosine. Methanosarcina acetivorans is the proposed species. C2A is the type strain (DSM 2834, ATCC 35395).

Steer, B. L. and Patrick L. Abbott (1984). "Paleohydrology of the Eocene Ballena Gravels, San Diego County, California." Sedimentary Geology 38(1-4): 181-216.

The Ballena Gravels are remnants of a river system that flowed westward across the ancestral Peninsular Ranges during medial and late Eocene time. The gravels (actually conglomerate) are channelized fluvial deposits that built westward as alluvial fan (Poway Group), submarine canyon (Scripps Formation) and submarine fan (Jolla Vieja Formation) depositional systems. Because the integrated sedimentary system contains distinctive Poway rhyolite clasts of limited geographic and temporal extent the now separated component formations are recognizable on the San Diego coastal plain and on the Channel Islands. Paleogeographic reconstructions suggest a transport distance of about 315 km. Multiple techniques analysis suggests the channel gradient in the San Diego area was 12-18 m km-1 . Stream velocity, based on a competent particle size of 52 cm, ranges from 2.5 to 4 m s-1 . Eight equations based on slope and velocity generated estimates of channel depth at flood stage that vary from 2.5 to 4.5 m.

Walker, Roger P., Richard M. Rosser, D. John Faulkner, Lawrence S. Bass, He Cun-Heng and Jon Clardy (1984). "Two new metabolites of the sponge Dysidea amblia and revision of the structure of Ambliol B." Journal of Organic Chemistry 49(26): 5160-5163.

Ambliol C, ambliofuran, pallescensin A, and pallescensolide were isolated from a sample of Dysidea amblia collected at Point Loma. The structure of ambliol C was determined from a single-crystal X-ray diffraction study performed on the ester 13 and that of pallescensolide from H NMR and other spectral data. The structure of ambliol B, one of five metabolites obtained from D. amblia collected at Scripps Canyon, was reassigned. X-ray diffraction analysis of the acid 14 showed that ambliol B contained a trans-fused decalin ring system rather than the cis ring junction proposed previously.

Graham, S. A. and S. B. Bachman (1983). "Structural controls on submarine-fan geometry and internal architecture: upper La Jolla fan system, offshore southern California." Bulletin of the American Association of Petroleum Geologists 67(1): 83-96.

Three bathymetrically prominent conduits supply sediment to the upper La Jolla fan system from stream and nearshore littoral drift-cell sources. La Jolla Canyon is the main feeder to the fan. Seismic profiling data confirm and previously reported erosional character of the channel and constructional nature of flanking levees. Newport canyon-channel, northerly feeder to the upper La Jolla fan system, is a single well-defined channel with flanking constructional levees where it lies in a structurally controlled trough. The position of Loma sea valley, southern feeder to La Jolla fan system, is tightly controlled by the structure of the steep flank of Coronado Bank. Seismic data demonstrate that the La Jolla fan system comprises a complex interleaved set of sediment wedges. The system presents an expansion from the simple radial growth pattern of fan sedimentation to a complex fan system built of a number of smaller interwoven radial growth components. La Jolla fan, offshore of San Diego, California, is a well-studied example of submarine-fan sedimentation, yet the internal architecture of the fan has remained poorly known. High-resolution seismic data, recorded in a 1 by 2 mi (1.6 by 3.3 km) grid, over much of the fan, allow better understanding of upper and middle fan features and processes, and of structural controls on fan sedimentation. Three bathymetrically prominent conduits supply sediment to the upper La Jolla fan system from stream and nearshore littoral drift-cell sources. La Jolla canyon (and contiguous La Jolla fan valley) is the main feeder to the fan. Seismic profiling data confirm the previously reported erosional character of the channel and constructional nature of flanking levees. These data also reveal that the position of the channel is controlled by the geometry of a buried, hard-rock structure. Seismic data demonstrate that the La Jolla fan system comprises a complex interleaved set of sediment wedges derived from multiple sources and woven around the wrench tectonic fabric of uplifts and basins of the southern California borderland. Thus, La Jolla fan system presents an expansion from the simple radial growth pattern of fan sedimentation to a complex fan system built of a number of smaller interwoven radial growth components. Despite these complexities, lithofacies patterns are in part predictable for the La Jolla fan system. Faultbounded uplifts form long-

lived barriers to sediment dispersal and enhance channel development along their flanks. Multistory channel complexes, detectable seismically, commonly occur in these structurally controlled positions adjacent to wrench related uplifts.

McAllister, T. P. and J. V. Wilson (1983). Design and installation of a subsurface trimoor over Scripps and La Jolla canyons. Proceedings of the 2nd International Offshore Mechanics and Arctic Engineering Symposium. pp. 3.

McAllister, T. P. and J. V. Wilson (1983). The design and installation of a subsurface trimoor over Scripps and La Jolla canyons. Am. Soc. Mech. Eng., Pap. 6th ASME energy sources technology conference and exhibition, Houston, TX. pp. 282-289.

As subsea suspended cable structure technology develops, suspended cable structures are becoming a practical means of supporting oceanographic instrumentation systems. A cable structure is presented that suspends a data collection system into a 2,500-ft (760 m) wide submarine canyon. Extensive computer simulations were used to estimate mooring line tensions, anchor loads, and the ability of the structure to hold the payload in the required location. The effects of mooring angle, line size, oceanic environment, and vessel attachment to the structure are discussed. The installation and the capability to fine-tune the final configuration are also discussed.

Pawka, S.S. and Robert T. Guza (1983). Coast of California waves study -site selection. San Diego, CA: Scripps Institution of Oceanography.

Smith, C. R. and T. M. C. Present (1983). "In vivo marking of shallow-water and deep-sea amphipods by ingestion of bait mixed with fast green." Marine Biology 73(2): 183-192.

Seven vital stains were mixed with fish muscle and fed to a sublittoral lysianassid (Orchomene sp. A collected in Scripps Canyon off La Jolla, California, USA between August 1978 and August 1981) in the laboratory to test the utility of these dyes as feeding labels for scavenging amphipods. Fast-green FCF proved to be the most effective of the stains tested > 90% of starved amphipods fed fast-green-stained bait (Scomber japonicus muscle) for as little as 1 h exhibited a conspicuous green coloration along the digestive tract, which lasted an average of greater than or equal to 35 d. The ability to label animals with such a single, short exposure interval makes this dye especially suitable for marking scavengers attracted to bait. Fast green efficiently stained this amphipod over a broad range of concentrations (1-8% by weight in water) and feeding regimes, and had no significant effects on survivorship or activity of laboratory-held organisms. Nile blue A was also an acceptable feeding label for Orchomene sp. A for time scales of about 1 wk.

Additional laboratory and field tests between Aug., 1978 and Aug., 1979 indicated that fast green is an effective feeding stain for 2 bathyal species (Orchomene sp. B and O. plebs from the Ross Sea, Antarctica) and 3 abyssal species (Eurythenes gryllus, O. gerulicorbis and Paralicella caperesca from the central North Pacific Ocean) of amphipods. Field labeling of amphipods at 58,00 m in the central North Pacific Ocean with fast green demonstrates that feeding stains may be used readily as in situ marking agents for population studies of scavengers in remote environments.

Warner, Jon A., Charles Areneson, Roswell W. Austin, Douglas Bailey, George Huszar, Peter James, Ronald R. McConnaughey, Kenneth Nealson and Edwin A. Stephan, Jr. (1983). "Scripps Canyon sea structure: A design and deployment for the study of oceanic bioluminescence." Marine Technology Society Journal 17(4): 40-47.

At the Scripps Institution of Oceanography, two research groups with similar interests in the study of bioluminescent behavior of deep water organisms and in the quantitative and qualitative measurement of bioluminescence over long periods of time, have avoided some of the previous difficulties in the study of in situ bioluminescence by constructing a subsurface field station. Connected to a shoreside laboratory via submarine cable, this station has several advantages. It provides a vertically stable platform from 18 m to 200 m of depth, ample electrical power, a powerful data handling system including a large number of control functions, high digital telemetry rates, and integrated computer data storage and processing. Here the authors describe the design considerations, construction, deployment sensors, telemetry, and control systems currently in use for photometric measurements.

Gordon, R. L. (1982). "Internal modes in a submarine canyon." Journal of Geophysical Research 87(C1): 582-584.

A simple analytical model is presented for internal waves in a slot of variable width. This model is used to explain the vertical wave length, directional character, and amplitude enhancement of internal waves observed near the axis of La Jolla Canyon.

May, Jeffrey A. (1982). Basin-margin sedimentation: Eocene La Jolla Group, San Diego County, California. Ph.D. dissertation, Rice University.

Continental to deep-marine facies transitions, eustatic versus tectonic controls on basin-margin stratigraphy, shelf-edge unconformities, and depositional mechanisms along basin margins were investigated for Middle Eocene strata, San Diego County. Coeval fan delta, nearshore, offshore, shelf, slope, submarine canyon, and proximal submarine fan facies indicate steep paleobathymetric gradients. Mass-transport processes dominated the canyon-fan system: sandy and muddy debris flows, fluidized and liquefied flows, grain

flows, high- and low-density turbidity currents, slumps, and rockfalls. The submarine canyon fill is tripartite and fining-upward, representing progressive detachment from a nearshore source. Planar- to convolute-laminated sandstone overlies a basal amalgamated pebbly sandstone. Lithologically variegated cross-cutting channels to 100's of meters wide cap the sequence. A qualitative sand budget indicates the pebbly sandstone bypassed the wave zone, directly tapping an unsorted fluvial source. Residual lag deposition predominated. The coarsest fraction (0 to 3 (phi)) was also trapped and deposited by traction in the paralic zone, whereas intermittent suspension removed the 3 to 4 (phi) component onto the shelf. Size-sorting occurred downcanyon. Traction and intermittent suspension characterized inner-fan channel deposition. Lag plus traction and suspension constituents distinguish mid-fan channels. Eustacy primarily controlled stratigraphic development. A depositional "hemicycle" of 9-10 m.y. corresponds to Vail et al.'s (1977) supercycle Tb. Punctuation by marine progradation was concurrent with an intervening eustatic fluctuation. Subaerial notching of the shelf edge coincided with the Late Penutian sea level drop. During the subsequent rise, canyons eroded headward and a thin, retrogradational sequence was deposited. Coarse-grained, nearshore accumulations of the Early Ulatisian highstand were flushed basinward, responding to a slight sea level fall; submarine fan progradation resulted. After minor retrogradation, a Late Ulatisian to Early Narizian highstand induced thick, progradational development. Similar stratigraphic sequences developed simultaneously in other Pacific margin coastal basins. This suggests primary eustatic control on sedimentation and/or simultaneous continental-margin uplift and subsidence. Variations in rates of and absolute paleodepth changes indicate local tectonics. Combining global sea level fluctuations and resultant depositional patterns can provide a powerful tool in frontier exploration.

Shepard, Francis P., Robert F. Dill and Ulrich von Rad (1982). "Physiography and sedimentary processes of La Jolla Submarine Fan and Fan Valley, California." AAPG Repr Ser (Tulsa) 26: 370-400.

Anon (1981). "Scripps Studies Bioluminescence With Underwater Station." Sea Technology 22(4): 53-54.

Marine Biologists at Scripps Institution of Oceanography are collecting data on fish and other marine organisms that biologically produce light - or bioluminescence - with a unique underwater research station. The station utilizes a large buoy, anchored directly over the Scripps Submarine Canyon, at approximately 14 meters below the surface. The buoy is held in place by three steel cables, each tied to base plates and weighted down with four 362-kilogram locomotive wheels. By use of a winch and umbilical, instruments capable of collecting data on bioluminescent organisms can be lowered to a maximum of 183 meters below the bouy. In this way, an entire column of water can be surveyed in about 30 minutes. The instruments can be positioned at the specific depths the scientists want to study further.

Huntley, D. A., R. T. Guza and E. B. Thornton (1981). "Field observations of surf beat, Pt. 1, Progressive edge waves." Journal of Geophysical Research 86(C7): 6451-6466.

Nineteen biaxial electromagnetic current meters have been used to determine the longshore and on/offshore structure of currents at surf beat periods (1-4 min). The sensors formed two linear arrays, a long-shore array within the surf zone and an on/offshore array stretching from the shoreline to well beyond the breaker line. Analysis of the longshore current components yields a clear picture of progressive low-mode edge waves, with frequency-wavenumber dispersion relations that are in remarkably good agreement with predictions. Some separation of edge wave modes is found, with mode zero energy dominating in the frequency band 0.006 and 0.011 Hz and mode one between 0.015 and 0.025 Hz. On/offshore currents present a different picture which, while not inconsistent with the longshore currents, suggests that other sources of energy are also important to the on/offshore currents. These include standing edge waves probably formed by reflections at nearby Scripps Canyon and motions that are nonresonantly forced by incoming wave groups.

Shepard, Francis P. (1981). "Submarine canyons: multiple causes and long-time persistence." AAPG Bulletin 65(6): 1062-1077.

The actual investigation of submarine canyons as field work was begun about 50 years ago. A large amount of factual information has accumulated as a result of operations of deep diving vehicles, first in the Pacific Coast canyons and more recently in the East Coast canyons. Taking the results of these recent dives and combining them with earlier investigations, including much work done by the French in the Mediterranean as well as our extensive studies off California and Baja California, we can now say with some confidence that these amazing deep excavations into the sea floor off so many coastal areas can be explained. New methods such as side scanning have also given us a greater understanding of the exact character of submarine canyons, particularly in the Bay of Biscay. The development of multichannel sonar has greatly increased our knowledge of the nature of continental margins and hence their history. This has given us more insight into the history of canyon development, particularly off the east Coast where drilling for oil and gas has become so important. In the past we have seen a great variety of hypotheses for explaining submarine canyons. Unfortunately almost all of these have been based on information from a small selection of the canyons, usually from one area. From the new information, it is evident that canyons are of composite origin and that many of the hypotheses suggested in the past were partly correct but did not appreciate that coordination of other processes was required. Thus there is growing evidence that, in the history of many canyons, there was a period in which subaerial erosion was an important precursor, but that present features are predominantly the result of marine erosion. Those advocating turbidity currents as the unique cause of canyons failed to appreciate that debris flows down the incipient valleys, as well as other types of landslides, could be an

almost equally important factor in marine erosion. The great effect of biologic activity on the rock walls of incipient canyons has been almost completely neglected in explanations, and various types of currents such as those of the tides have been left largely out of the picture. Perhaps the most important feature absent in these various hypotheses has been the realization that canyons may well be the result of a long period of formation, much longer than the short episodes of Pleistocene glacial sea-level lowering usually considered explanation enough of these giant features which commonly cut into hard crystalline rock. New information is showing that the canyons may date back to at least the Cretaceous. Seismic profiles suggest that La Jolla Canyon follows a fault and the offset where Scripps Canyon enters La Jolla Canyon suggests that there may have been right-lateral movement so that Scripps Canyon may be offset and continue to the northwest where there is a right-angled bend in La Jolla Canyon. The straightness of the narrow Scripps Canyon is also suggestive of rifting action. We observed a pile of boulders in Scripps Canyon with a steep descent below on one side, and some months later thay had disappeared. Surely a powerful flow had intervened. The auto body placed by Dill shortly prior to 1964 in the same canyon, and anchored to the walls by heavy weights, could not be found a few years later when repeated dives were made down this canyon. Slumping could have been the cause, but it seems more probably by all other evidence that it was carried away by turbidity currents and debris flows.

Shepard, Francis P., Gary G. Sullivan and Fergus J. Wood (1981). "Greatly accelerated currents in a submarine canyon head during optimum astronomical tide-producing conditions." Shore and Beach 49(1): 32-34.

Until recently, no records had been made in shallow water during times when the maximum tidal influences might be expected as the result of astronomical conditions being optimal for producing tidal currents. Such circumstances would include alignment of the Earth with the Moon and Sun during a time of their close proximity and an optimal zenith angle of the Moon at the place of measurement. Using the information from Wood for a check on the time of such an optimal tide in La Jolla Canyon head, off southern California, the authors obtained, around the end of January 1979 records providing a subsurface confirmation of the special conditions designated in Wood's treatise as proxigean spring tides. The records were obtained at an axial depth of 48 m in a locality where several records were made on previous occasions. The effects of the proxigean spring tides combined with an optimum zenith angle of the moon by comparing them with records of canyon currents obtained from the head of La Jolla Canyon in California at approximately the same location and height above bottom under normal tidal conditions are demonstrated. Shoreward velocities of 82 cm/sec were recorded in La Jolla Canyon during proxigean spring tides, which occur, on the average, only once in several years. Such strong onshore currents may result in coastal flooding and cause accelerated sedimentary erosion. Additional studies of these unusual tidal currents are needed.

Walker, Roger P. and D. John Faulkner (1981). "Diterpenes from the Sponge Dysidea arnblia." Journal of Organic Chemistry 46(6): 1098-1102.

Collected from Scripps Canyon, the marine sponge Dysidea amblia contained two major metabolites, ambliol-A and ambliol-B, and three minor metabolites, ambliofuran, ambliolide, and dehydroambliol-A. The diterpenes are the first to be isolated from a Dysidea species. Examination of individual animals indicated that some contained ambliol-A while others contained ambliol-B, although the individuals could not be distinguished by means of classical taxonomy.

Wood, Fergus J. (1981). "Astronomical and Tidal Analyses Of Unusual Currents In a Submarine Canyon During Proxigee-Syzygy Alignment." Shore and Beach 46(1): 35-36.

Large currents measured in La Jolla Canyon on Jan. 29, 1979, are attributable to a very close perigee-syzygy alignment of the Sun, Moon, and Earth. The unusually accelerated upcanyon currents observed at a depth of 48 m along the axis of the La Jolla submarine canyon have a number of astronomical and other features--including a very close perigee-syzygy (proxigee-syzygy) alignment of Sun, Moon, and Earth--which are explained. As noted in this tide-reinforced test example, during the period January 27-February 6, 1979, current meters were emplaced at depths of 1, 3, and 10 m above the bottom, at approximately the same location in the La Jolla Canyon used on previous occasions of more ordinary tides. The time of the first high-velocity surge lagged the mean epoch of perigee-syzygy by 33.5 hr because of the combined effects of parallax and phase age.

Zlotnick, Elias (1981). Upper Cretaceous deep-sea fan and related lithofacies, San Diego, California; distribution and implications. Masters thesis, San Diego State University.

Board, California State Water Resources Control (1980). California marine waters, areas of special biological significance, reconnaissance survey report. San Diego Marine Life Refuge, San Diego County. California State Water Resoures Control Board. Water Quality Monitor. Rep.

Areas of Special Biological Significance (ASBS) have been designated by the California State Water Resources Control Board in its effort to adopt water quality control plans for wastes discharged to ocean waters. To evaluate the protection status of marine resources at San Diego Marine Life Refuge, an ASBS, a reconnaissance survey was conducted that integrated all available hydrographic, geologic and biological information. Means of investigation included a search of records, map reconnaissance, shoreline and underwater observations, interviews, and a literature review. There appeared to be no actual point source pollution threats except that of sewage spills during periods of heavy

rainfall. Sailing, shore fishing, snorkeling, scuba diving, surfing, body surfing, and tide-pooling are some of the water-use recreational activities that occur within the Refuge, which is adjacent to Scripps Institution of Oceanography in La Jolla. The study suggested periodic but regular monitoring of the ASBS to evaluate accurately the status of protection afforded the area. The study also urges consideration be given to extending the boundaries of the Refuge to include the head of Scripps Canyon.

Board, California State Water Resources Control (1980). San Diego Marine Life Refuge, San Diego County. California State Water Resources Control Board. California Marine Waters, Areas of Special Biological Significance Reconnaissance Survey Report. Water Quality Monitoring Report N. 1980.

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Hess, G. R. and William R. Normark (1980). "Quaternary styles of California submarine fans." American Association of Petroleum Geologists Bulletin 64(3): 443-444.

Kennedy, Michael P., S.H. Clarke, H. Gary Greene and M. R. Legg (1980). Recency and character of faulting offshore from metropolitan San Diego, California; Point La Jolla to Baja California. San Francisco, CA: California Division of Mines and Geology.

Detailed marine geophysical surveys of the Rose Canyon, Coronado Bank, and San Diego Trough fault zones indicate that the inner southern California borderland offshore from metropolitan San Diego is underlain by a Quaternary, right-lateral, strike-slip tectonic regime geologically manifest in youthful faults and an alternating series of compressional and tensional structural highs and lows. Seismic reflection profiles indicate that these fault zones displace acoustically transparent (water saturated and unconsolidated) surficial

deposits on the sea floor and locally are associated with bathymetric relief. Fault scarps (questionably fault-line scarps) more than 100 m in height have been delineated within the area studied. The Rose Canyon fault zone, regionally a part of the Newport-Inglewood-Rose Canyon-Vallecitos-San Miguel fault system, is characterized by a complex series of northwest trending Quaternary faults. Faults in this zone displace acoustically transparent (Holocene) sediment on the sea floor offshore from La Jolla on the north and offshore from Coronado near San Diego Civic Center on the south. Many of these faults are associated with bathymetric relief thought to be at least partly tectonic in origin. Although the Rose Canyon fault zone is considered seismically "quiet," the section between San Diego Bay and Mexico has been characterized by low level seismicity over the past three decades. The Coronado Bank fault zone, regionally a part of the Palos Verdes Hills-Coronado Bank-Agua Blanca fault system, is characterized by a series of both left- and right-stepping, en echelon, mostly northwest-trending, subparallel faults. Approximately 20 km of right-lateral strike slip is suggested from onshore stream offsets, offshore bathymetric displacements, and character of drag seen on reflection profiles. Moderate seismicity is associated with the Coronado Bank fault zone trend along much of its mapped length. The San Diego Trough fault zone, regionally a part of the San Pedro-San Diego Trough-Maximinos fault system, is characterized by northwest trending faults that juxtapose acoustic basement on Thirty Mile Bank with acoustically transparent (Holocene?) sediment in the San Diego Tough. A continuous, 22 km long fault within the San Diego Trough fault zone has been delineated in the central part of San Diego Trough, where it shows continuous sea floor relief. Sediment cut by faults in the area has been divided into three informal units based on superposition and acoustic properties. The youngest of these, inferred from correlations to be Holocene and late Pleistocene in age, has a velocity of 1.4-1.7 km/sec, and generally is acoustically transparent. The intermediate unit, inferred to be a Plio-Pleistocene succession, has moderately strong reflection character, generally underlies a veneer of the acoustically transparent sediment, and has a velocity of 1.7-1.9 km/sec. The oldest unit, Late Cretaceous and early and middle Tertiary in age, has extremely strong reflection character, and has velocities of 1.9-2.2 km/sec. Other data used in the study include high resolution sparker records collected aboard the U.S. Geological Survey R/V Polaris in 1970 (Moore, 1975), and 12 KHz, 3.5 KHz Uniboom, and 120 KJ sparker records collected aboard the U.S. Geological Survey R/V Sea Sounder in 1978 and 1979 (Greene and others, 1979). The R/V Sea Sounder data are of exceptionally high quality and have been used where possible as a standard for comparison with the other, more closely spaced profiles of this study

Koslow, Julian Anthony (1980). The Feeding Of Schools Of Northern Anchovy (Engraulis Mordax), and Community Structure and Diurnal Migratory Behavior In Marine Zooplankton. Ph.D. dissertation, University Of California, San Diego.

Size-selective feeding by planktivorous fish has been hypothesized to regulate the size and species structure of freshwater zooplankton communities. The diurnal migratory activity noted in many large zooplankton has also been related to the predation upon them by fish. The mechanisms regulating the structure of zooplankton communities and

the migratory behavior of large zooplankters are examined here in the context of marine systems. In Chapter I, I characterize the feeding selectivity of schools of northern anchovy (Engraulis mordax). Direct field measurements showed consistent size-selective feeding. At low-to-moderate prey densities, the schools consumed 35-50% of the total zooplankton biomass; the consumption approach 100% of the larger zooplankters. Preference for a particular species was found in only one instance. The northern anchovy's feeding is adequately described as a linear function of prey size alone. The degree of selectivity is inversely related to the size-range of available prey. In Chapter II, a simulation model of a marine zooplankton community is developed. The model contains a large and a small herbivore (LH and SH) (also treated as omnivores), an invertebrate carnivore (IC), and planktivorous fish. The size, growth and reproduction of the LHs and SHs are modelled upon the characteristics of large and small, predominantly herbivorous copepods. Mortality of the herbivores is a function of the predation upon them by both the ICs and fish. The feeding of the IC is modelled upon the predatory characteristics of chaetognaths and predatory marine copepods. Growth and reproduction in the ICs is based entirely upon their prey consumption and metabolism. The algorithm for the predation of the fish upon the plankton is derived from Chapter I. The standing stock of planktivorous fish remains constant during each simulation. The relative abundance of SHs and LHs is a function of both their carrying capacity and the standing stock of planktivorous fish. LHs dominate when productivity is high and fish stocks are relatively low; SHs dominate under the opposite conditions, where the LHs' productivity is outweighed by their mortality to the fish. Results of the model are: (1) general consistency with observations of the seasonal succession of LHs and SHs; (2) In light of the model, changes over the past two decades in the zooplankton community of the North Sea are related to changing phytoplankton and fish stocks; (3) The model also indicates that the intensity of migratory activity of LHs should be an inverse function of the environmental carrying capacity for their production. In the final chapter, the migratory activity of three common zooplankters is examined in relation to a seasonal progression from high (spring) to low (summer) primary productivity. La Jolla Canyon concentrates the migratory zooplankton descending into it each day in the nearshore zone. A vertical migration index (VMI) is developed: the relative concentration of migratory to non-migratory plankton within La Jolla Canyon relative to their relative concentration at a nearby, non-canyon station. The patterns of the VMIs for the migratory stages of Calanus pacificus, Rhincalanus nasutus,and Euphausia pacifica from April - August, 1967 are consistent with previous observations of migratory activity in these zooplankters. Principal component analysis (PCA) is performed on 13 hydrographic and biological parameters measured weekly at these stations during the study period. The first PC is a measure of upwelling activity and diatom bloom conditions. The VMIs for C. pacificus (C IV - C VI) are significantly and negatively related to the first PC; the VMI for E. pacifica juveniles and adults is highly significantly and positively related to this PC. The VMIs for R. nasutus (C III - C VI) show no significant relation to any PC. While upwelling and productivity appear to be important to their migratory behavior, the relationship is not a simple one.

Lohmar, John M., J.A. May, J.E. Boyer and John E. Warme (1979). Shelf edge deposits of the San Diego embayment. IN: Eocene depositional systems, San Diego, California. P. L. Abbott. Los Angeles: Pacific Section of the Society of Economic Paleontologists and Mineralogists: 15-27.

not sure if on the Canyon

Planners, Chambers Consultants and (1979). Outer Continental Shelf Hard Minerals Leasing: Economic Feasibility of OCS Mining for Sand and Gravel: San Pedro Shelf, Offshore Los Angeles, and San Diego Shelf, South of La Jolla Canyon. Appendix 16. Program feasibility document (Final). For US Geological Survey. NTIS PB81192684; also available in set of 17 reports from NTIS: PC E99, PB81-192544; See also Appendix 15, PB81-192676, and Appendix 17, PB81-192692.

The objective of the study was to determine the economic feasibility of mining OCS sand and gravel at ......the San Diego shelf south of La Jolla Canyon. All of the systems analyzed showed a negative net present value of after-tax cash flows, using a risk adjusted interest rate of 20%. Mining systems analyzed were clamshell dredging, bucket ladder dredging and hydraulic suction dredging.

Shepard, Francis P. (1979). Currents in submarine canyons and other types of seavalleys. IN: Geology of Continental Slopes, Society of Economic

Paleontologists and Mineralogists Special Publication No. 27. L. Doyle and O. H. e. J. and Pilkey. Tulsa, Oklahoma: 85-94.

Shepard, Francis P., Neil F. Marshall, Patrick A.. McLoughlin and Gary G. Sullivan (1979). Currents in submarine canyons and other seavalleys. Tulsa, Oklahoma: American Association of Petroleum Geologists.

Extensive discussion of canyon currents in several systems and includes sections on La Jolla and Scripps canyons. States that currents in canyons are comparable to tidal currents and show a reversal of direction at intervals comparable to those of the reversing tides, moving alternately up and down the valley axes with the period of reversal at intervals comparable to the reversal of the tides. La Jolla and Scripps Canyons commonly start to fill rapidly with sediment but the process is interrupted by turbidity currents and partly by a slow creep. Shallow stations in La Jolla Canyon had net upcanyon current flow and most of the deeper stations had net downcanyon flow. Internal waves moving up La Jolla canyon were measured. Scripps Canyon was more difficult to study. Scripps Canyon also had net downcanyon current flow with net upcanyon flow at shallow stations. Observations supporting the existence of turbidity currents in Scripps

Canyon are presented that show a fast downcanyon flow preceding a period of no current and then, soon afterward, stopping completely.

Shepard, Francis P., Fergus J. Wood and Gary G. Sullivan (1979). Perigean spring tides and unusual currents in La Jolla submarine canyon. Abstracts with Programs, Annual Meetings, The Geological Society of America. 1979 Annual Meetings, The Geological Society of America (92nd), San Diego, California, Geological Society of America, Boulder, Colorado. pp. 515.

During optimum conditions for large tides off La Jolla, at the end of January, 1979, currents were measured at three levels near the floor of La Jolla Canyon at a depth of 48 meters, yielding data differnt from any obtained during ten years of study of canyon currents. At both one and three meters above the bottom, simultaneous pulses of upcanyon flow attained velocities up to eighty centimeters per second, and an upcanyon flow at a slower speed was observed at ten meters above bottom. The velocity is almost twice that observed in an upcanyon direction in any canyon and about eight times normal for this canyon. Two peak velocities occurred with an interval of 25.7 hours (or 24.2 hours, surge to surge), clearly relating the currents to the higher high-water phase of the accompanying perigean spring tides (tidal day=24.80 hours). Measurements were made at a geocentric zenith distance of the moon which maximized the local tidal-force conditions. No such clear relationship to the tidal interval previously exists in the alternating-direction pulses of flow characteristic for such shallow water in canyon heads. The alternations had usually been much more frequent, and the only exception had been where very large tides were encountered in the head of a small submarine valley off the Fraser Delta. These measures of accelerated subsurface currents reinforce existing evidence that especially close alignment of sun, moon, and earth at perigee (proxigee)-syzygy augment rates of tide growth and, when accompanied by supporting winds, can amplify and prolong tidal conditions contributory to coastal flooding. Sediment erosion by such ocean-floor currrents may weaken the foundations of offshore platforms. A means of removing the recent sediment from submarine canyon heads is also indicated.

Waggoner, James Allen (1979). Unconsolidated shelf sediments in the area of Scripps and La Jolla Submarine Canyons. Masters of Science in Geology, San Diego State University.

A survey of unconsolidated sediment distributions on La Jolla mainland shelf was made using sub-bottom seismic profiling and jet probing. The unconsolidated sediments around Scripps and La Jolla Canyons cover the shelf in a wedge-shaped deposit which reaches its maximum thickness in 35 to 55 meters of water. To the north of Scripps Canyon, the unconsolidated sediments show an increase in maximum thickness from 1 to 4 meters as compared to the sediment isopach of the area done by Henry in 1976. The total increase in sediment volume is approx 970,000 cubic meters. Sediment

accumulations up to 21 meters thick on the intercanyon shelf show no significant increase in sediment thickness since 1976. Three sediment slumps occur along the rims of the intercanyon shelf. The lack of sediment increase on the intercanyon shelf, combined with the evidence of sediment slumping along the canyon rims, may indicate that sediments brought up to the intercanyon shelf by rip currents are redistributed laterally. South of La Jolla Canyon the unconsolidated sediments show no significant increase in thickness since 1976. Fossils collected by jet probing in 6 to 11 meters of water around the canyon heads were all shallow water, near-shore types with a maximum time range of Pleistocene to Holocene. No definitive Pleistocene faunas were found. North of Scripps Canyon, terraces occur in 24 meters and 46 meters of water. Discontinuous high intensity reflectors on the terrace abrasion platforms probably represent relict Pleistocene terrace deposits of cobbles or boulders. Relict Pleistocene deposits in the area are probably limited to the terrace abrasion platforms with the majority of the shelf unconsolidated sediments being recent. An area of bedrock slumping occurs at the seaward edge of the intercanyon shelf in 55 to 58 meters of water. The slump has a linearity which parallels the Rose Canyon Fault and may be related to it by another minor fault. The increase in unconsolidated sediment thickness observed in the areas is attributed to mass deposition of sediment on the mainland shelf during the Winter-Spring 1978 period of increased rainfall. During this period large volumes of sediment were observed being flushed from San Diego County estuaries to the mainland shelf.

Marshall, Neil F. (1978). Large storm-induced sediment slump reopens an unknown Scripps Submarine Canyon tributary. IN: Sedimentation in submarine canyons, fans, and trenches. D. J. Stanley and K. Gilbert. Stroudsburg, Pa: Dowden, Hutchinson and Ross: 73-84.

Towards the end of May 1975, an estimated one hundred thousand cubic meters of sediment slumped opening a tributary canyon approximately four hundred meters in length, about eight to thirty meters deep and as much as one hundred meters wide. This exposed tributary was on the south flank of Scripps Canyon downcanyon from the junction of North and Sumner branches and pointing towards the end of Scripps Pier. Exposed bedrock indicated that a tributary previously existed and had been filled. Sediments were supersaturated with little cohesion after the slump; the sediment surface was pockmarked which may reflect the escape of pore water. Sediments approached their previous state of compaction after six months. The occurrence of a slump in Scripps Canyon provided an opportunity to develop concepts pertaining to the initiation of such slumps and their significance to sediment transport to the deeper sea floor. Accumulating sediments modify the erosional cross-sections of narrow canyons by forming deposits with slopes that trend upward from the steeper bedrock walls. These slopes will, if undisturbed, lie at the angle of repose that is dictated by the particular internal cohesive forces of the sediment. The angle of repose of sediment is also affected by the binding effect created by bioturbate structures and organic growth, the variation of sediment type, and the deposition of salts. As deposition continues, these slopes become oversteepened, and slumps will occur. Differential wave pressure, caused by large storm

waves, is suggested as a mechanism for the initiation and headward advance of shallow water slumps on slopes of relatively low gradient. The storm precipitating this slump was not of higher energy than storms of previous winters and springs; therefore other conditions were necessary to set the stage for this slump. This slump is likely to have formed a turbidity flow transporting sediment considerable distance downcanyon. The findings of this and previous studies indicates two types of marine slumps: gravitationally induced and liquefaction. Those slumps that take the form of valleys such as this May 1975 slump are probably related to large wave- or earthquake-induced liquefaction slumping, while those that form large arcuate curves near slope breaks are probably related to gravitation factors although earthquake shock could aid as well.

Nelson, C. Hans, William R. Normark, Arnold H. Bouma and Paul R. Carlson (1978). Thin-bedded turbidites in modern submarine canyons and fans. IN: Sedimentation in Submarine Canyons, Fans, and Trenches. D. J. Stanley and G. Kelling. Stroudsbury, PA: Dowden, Hutchinson & Ross: 177-189.

Thin-bedded sand and silt turbidites are present in nearly all physiographic environments of modern submarine canyons and fans. In Holocene time, they are common within channel deposits because high stands of sea level restrict coarse-grained sediment supply in many canyon-fan systems, and typical channel fill of thick-bedded turbidites is not developed. During the late Pleistocene period, most canyon-fan valley systems were active pathways for the transport of coarse-grained sediment, and nonchannelized parts of fans were built by overbank deposition of thin-bedded turbidites. Thin-bedded Pleistocene turbidite facies of presently existing canyons and fans exhibit sufficient differences in geophysical and sedimentological characteristics to define distinct depositional environments. In channelized areas of upper and middle fans, thin-bedded turbidites are associated with thick-bedded thalweg (a line along the deepest part of the valley) sands and gravels; they are found in thin sequences that pinch out laterally and are subject to cutting, filling, and slumping from channel walls. Individual turbidites contain Bouma T(c-e) sequences, cross-lamination, ripple drift, starved ripples, and lenticular sands. Sand:shale ratios are high because the fine-grained interbeds of turbidite and/or hemipelagic mud are thin. Thin-bedded Pleistocene turbidite facies from interchannel, inter-lobe, and levee crests (on some fans) are finer grained and more continuous laterally than those from adjacent intrachannel or mid-fan lobe (suprafan) areas. They exhibit thicker stratigraphic sequences with lower sand:shale ratios and are less dominated by cross-lamination. Distal turbidites of basin plains occur in sequences hundreds of meters thick that are laterally continuous for tens of kilometers. Parallel lamination is the most characteristic sedimentary structure, and low sand:shale ratios prevail because of well-developed pelagic mud interbeds. Includes side scan and deep-tow profiles of valley meander on La Jolla Submarine Fan showing slump deposits of semiconsolidated sediment.

Shepard, Francis P. and Neil F. Marshall (1978). Currents in submarine canyons and other sea valleys. IN: Sedimentation in submarine canyons, fans, and trenches. D. J. a. K. Stanley, Gilbert. Stroudsburg, Pa.: Dowden, Hutchinson & Ross: 3-14.

Incorporates data from La Jolla and Scripps Canyons. The vast quantities of sediment carried down canyons is demonstrated by the huge fans at canyon mouths. Near-bottom currents (rarely exceeding fifty cm/sec) flow almost continuously up- and downcanyon, with net flow commonly in a downcanyon direction and with sufficient speed to transport large quantities of fine sediment down the canyons. In the deeper portions of canyons and in regions with large tidal ranges, the length of these periods of flow and times between reversals show a close relationship to the tides, whereas in shallow canyon heads and in regions with small tidal ranges, the unidirectional flow and time between reversals is much shorter. The more frequent alternations in the direction of flow and length of periods of flow may be caused by internal waves and internal tides as is shown by tracing their patterns along the canyon axes. Periods of crosscanyon flows are observed particularly in canyons with wide floors, and their periods are in some cases related to phases of the tide. Much faster downcanyon flows are observed at infrequent intervals and are interpreted here as turbidity currents. Such flows have been inferred from the loss of current meters during storms and were observed in current meter records with downcanyon speeds of up to about two hundred cm/sec. These flows occur in association with onshore storms, high swell, and during periods of large discharge from rivers that have canyon heads at their mouths. That earthquakes cause large turbidity flows has yet to be documented by current meters.

VanBlaricom, Glenn R. (1978). Disturbance, predation, and resource allocation in a high-energy sublittoral sand-bottom ecosystem: experimental analyses of critical structuring processes for the infaunal community. PhD dissertation, Scripps Institution of Oceanography, University of California San Diego.

Chapter 4, Disturbance scale, natural history, and resilience: the response of a subtidal sand animal community to a large natural perturbation, studies the effect of a large slump into Scripps Canyon to the northwest. Marshall (1977) suggested that the slump was caused by sediment shear failure induced by the heavy seas of 20-21 May 1975, with storm swell of previous years contributing to physical instability in the sand bottom. Marshall found that the slump event formed a new valley, roughly 400 meters long and up to 100 meters wide, resulting from the movement of approximately 100,000 cubic meters of sand into Scripps Canyon. The new slump valley was initially bounded by steep sedimentary escarpments of one to three meters height. Within these boundaries the sediments were supersaturated with interstitial water. The surface of the semi-fluid bottom was littered with uprooted, moribund benthic animals, especially the pennatulid coelenterate Stylatula elongata and the onuphid polychaete Diopatra solendidissima, both of which were abundant in the affected area prior to the slump event. No undamaged individual Stylatula or Diopatra could be found within the valley. In the months following the formation of the slump valley, the abrupt boundary escarpment features were

smoothed and the interstitial water content of water sediments declined. This landslide near this dissertation's main study location served as a natural experiment to examine hypotheses regarding the importance of disturbance scale in patterning community resilience. Major differences were found in the response of the affected community to the large-scale disturbance relative to more frequent and localized perturbations. The differences were best understood in terms of certain natural history features of resident populations. The accommodation of some species to frequent small-scale disturbances was pre-adaptive for rapid response to the larger disruptive event. Species which respond slowly to smaller disturbances failed to rapidly occupy the larger event. This pattern was complicated by bathymetric distributions of some species which are early colonists of localized perturbations. Because of the insular character of the slump area, some early colonists were slow to penetrate the area affected by the larger disturbance. Finally is is argued that the timing of the large-scale perturbational events in the target community can markedly influence the form of numerical response curves.

Warme, John E., Richard A. Slater and Richard A. Cooper (1978). Bioerosion in submarine canyons. IN: Sedimentation in submarine canyons, fans, and trenches. D. J. Stanley and G. Kelling. Stroudsburg Pa: Dowden, Hutchinson & Ross: 65-70.

Erosion by invertebrates and fishes has been documented in canyons cut into continental shelves off Georges Bank and off Southern California by using observations and collections made with scuba and manned submersibles. A high diversity of bioeroders is present but they vary with geographic location, depth, and substrate. The process whereby borers erode rock outcrops, termed bioerosion, is in contrast with penetration and stirring of soft sediment by burrowers, or bioturbation, although the latter process is also important on the floors of canyons. The head of La Jolla Canyon is semi-consolidated Pleistocene mud at 15-30 meters with pholadid bivalves (Zirfaea) and large gaper clams (Panopea, Tresus), crabs, shrimp, ophiuroids, and other invertebrates boring and burrowing in the mud. Scripps Canyon is cut into much harder outcrops of calcarious and noncalcareous mudstone and sandstone of the Eocene Ardath Shale (formerly Rose Canyon Shale) with a different assemblage of borers. Pholadid bivalves are Penetella, Parapholas, Chacea, and Nettastomella and mytilid bivalves include Lithophaga and Adula. Other borers are polychaetes, sipunculids, crabs, and other molluscs with the initial larger boreholes by the bivalves whose borings are then interconnected by worms and crustaceans. Bioerosion may be the dominant process in penetrating, excavating and disintegrating exposed or loose bedrocks in these canyons.

Palmer, Harold D. (1977). Submersibles: geological tools in the study of submarine canyons. IN: Submersibles and their use in oceanography and ocean engineering. R. A. Geyer. Amsterdam: Elsevier: 279-295.

A major function of the research submersible is to provide a window into regions which cannot otherwise be examined with care and consideration for changing bottom conditions. The deep undercut in the La Jolla central valley is one example of a dive plan which was altered as a result of unexpected circumstances. Considerations regarding waste disposal on the continental shelves often include discussion of the canyons as 'natural conduits' to the deep ocean basins, and therefore ideal depositories for refuse which will be carried away from coasts. But current measurements and observations of sediment transport suggest that there may be significant transport up the cayons as well as down. Submarine canyons, play a complex role in shelf water circulation, and provide a habitat and nursery for economically valuable species. Therefore, they may not be considered as one-way conduits for waste disposal. In addition, in many other respects they influence physical and biological processes operating on the shelf and slope. Submersibles provide a key tool in evaluating the role of submarine canyons in the overall continental margin environment.

Saf'yanov, G. A. (1977). Experimental comparison of the lithologic characteristics of the Inguri (Black Sea) and La Jolla (Pacific Ocean) submarine canyons = Opyt sravnitel'noy kharakteristiki litologii podvodnykh kan'onov Ingurskogo (Chernoye more) i La Kol'ya (Tikhiy okean). IN: Paleogeografiya i otlozheniya pleystotsena yuzhnykh morey SSSR. P. A. Kaplin and F. A. Shcherbakov. Moscow: Izd. Nauka: 164-170.

Shepard, Francis P., Patrick A. McLoughlin, Neil F. Marshall and Gary G. Sullivan (1977). "Current-meter recordings of low-speed turbidity currents." Geology 5(5): 297-301.

Turbidity currents of high velocity may occur during catastrophic conditions, but our records suggest that currents of little more than 1 knot (=0.5 m/s) may be quite common in submarine canyons. Three current-meter records of such currents were obtained during an onshore storm at La Jolla, California, and two other locations. A pattern observed in all these occurrences included a preceding, relatively large, upcanyon flow, rapid buildup of the downcanyon turbidity current, a slow decay, and a following interval of no current. These currents may be particularly common where deltas have built across the continental shelf and large masses of sediment are being introduced into canyon heads. These relatively weak currents may transport large quantities of sediment down the canyon.

Dill, Robert F. (1976). Sedimentation and erosion in Scripps submarine canyon head. IN: Submarine canyons and deep-sea fans; modern and ancient. Benchmark papers in geology. J. H. Whitaker. Stroudsburg, PA: Dowden, Hutchinson and Ross. 24: 78-96.

Gordon, R.L. and Neil F. Marshall (1976). "Submarine canyons: internal wave traps?" Geophysical Research Letters 3(10): 622-624.

Kinetic energy of water currents near the axis of La Jolla submarine canyon is enhanced in a broad frequency band above tidal frequencies and below the Vaisala frequency when compared with water motions nearby but not within the canyon. This energy appears to be derived from first mode internal waves over the adjacent continental shelf.

Henry, M.J. (1976). The unconsolidated sediment distribution on the San Diego County mainland shelf, California. Masters thesis, San Diego State University.

Inman, Douglas L., C. E. Nordstrom and Reinhard E. Flick (1976). "Currents in submarine canyons; an air-sea-land interaction." Annual Review of Fluid Mechanics 8: 275-310.

Marshall, Neil F. (1976). "Large sediment slump reopens unknown Scripps Submarine Canyon tributary." AAPG Bulletin-American Association Of Petroleum Geologists 60(4): 695.

McHuron, Eric Jay (1976). Biology and paleobiology of modern invertebrate borers. PhD dissertation, Rice University.

Documents the species of molluscs, polychaete annelids, sipunculids, crabs and other borers infesting Scripps Canyon walls and describing their borings.

Menard, Henry W. (1976). Deep-sea channels, topography, and sedimentation. IN: Submarine canyons and deep-sea fans; modern and ancient. Benchmark papers in geology. J. H. Whitaker. Stroudsburg, Pa.: Dowden, Hutchinson and Ross, Inc. 24: 162-172.

Nelson, David C. (1976). Current ripples in Scripps Submarine Canyon's Sumner Branch. Geology 198B Senior Thesis. Undergraduate Research Reports, volume 28, part 2, San Diego State University.

A study was made to understand the role of ripples in mean size, sorting, skewness, and the transportation of sediment from the beach down to Scripps Canyon's Sumner Branch to depths of 70 feet. Measurements of the wavelength, height, and symmetry of the ripples were taken. Ripples were present only at depths between 25 and 40 feet. The ripple wave length was greater at 40 feet than at 25 feet due to the decrease in wave action. Sediment was coarser and less dense at the crest, and finer and heavier in the trough. Sediment size varied from coarsest at the beach to a gradual fining of sediment to a depth of 50 feet. Below 50 feet, a coarsening of sediment occurred extending to a depth of 70 feet, due to an increase in wave action as compared to adjacent areas. The sediment at 70 feet in the canyon is coarser than the adjacent shelf deposits north of the canyon at the same depth indicating coarse sediment transport down canyon from the beach.

Normark, William R. (1976). Growth patterns of deep-sea fans. IN: Submarine canyons and deep-sea fans: modern and ancient. J. H. Whitaker. Stroudsburg, PA: Dowden, Hutchinson and Ross: 220-235.

Palmer, Harold D. (1976). "Erosion of submarine outcrops, La Jolla submarine canyon, California." Geological Society Of America Bulletin 87(3): 427-432.

Observations made from a submersible operating within the sinuous central segment of La Jolla submarine canyon have provided spectacular examples of erosion at two outcrops below a depth of 300 meters. One outcrop displays extensive destruction through bioerosion of siltstone members. Burrowing and grazing activity of galatheid crabs has led to slumping and spalling where cavities cluster, intersect, or parallel the face of this outcrop. A second site on the outside wall of a right-angle bend in the canyon axis revealed an undercut extending 23 meters beneath the vertical canyon wall. A well-established encrusting fauna reaching to the canyon floor indicates that abrasive high-velocity currents have not occurred at this site for at least six months. The depth of this feature requires that the process responsible for such erosion take place on the sea floor. Sediment samples from the fan and fan valley below this part of the canyon reveal coarse deposits lacking features typical of turbidites, yet indicative of high-velocity submarine currents. It is concluded that the undercut is a relict erosional feature remaining from a previous period (Pleistocene) when runoff producing the latest rapid rise in sea level must have generated "submarine floods" charged with coarse detritus.

Shepard, Francis P. (1976). "Tidal components of currents in submarine canyons." Journal of Geology 84: 343-350.

Alternating up- and downcanyon currents in the heads of submarine canyons have high-frequency reversals, and, in general, the time interval between alternations increases with depth of the canyon axis until it approximates the period of semidiurnal tides. The depth at which this semidiurnal relationship is found is apparently related to the tidal range. According to available information, with a tidal range of 1.5 and 2.5 meters, the depth necessary to show the relationship between the current reversal period and the semidiurnal tide is usually between 250 and 350 meters; whereas, if the range is of the order of 1 or less, the depth necessary to develop the tidal relationship is as great as 1,500 meters. In three canyons with relatively large tidal range, records taken from depths of more than 1,400 meters have alternation cycles shorter than the period of the semidiurnal tide and more irregular than the records from depths between 250 and 1,400 meters. In the few available long-period records, the length of the current reversal cycle was found to be greater during spring tides than during neap tides. Cycles as long as the 25-hour diurnal tides were observed in portions of a few records where during large spring tides the heights of the two daily tides contrasted greatly. La Jolla and Scripps Canyons receive no mention in the text; figure one graphs canyon depth with average up- and downcanyon cycle length for several submarine canyons, and La Jolla Canyon is one of the canyons graphed.

Shepard, Francis P., Robert F. Dill and Ulrich von Rad (1976). Physiography and sedimentary processes of La Jolla submarine fan and fan-valley, California. IN: Submarine canyons and deep-sea fans: modern and ancient. J. H. Whitaker. Stroudsburg, PA: Dowden, Hutchinson and Ross: 185-216.

Byrd, R.E., R.W. Berry and P.J. Fischer (1975). "Quaternary geology of the San Diego-La Jolla underwater park." Abstracts with Programs, Geological Society of America 7(3): 300.

Marshall, Neil F. (1975). The measurement and analysis of water motion in submarine canyons. Ocean 75, Inst. Electr. Electron. Eng. pp. 351-356.

Techniques have been developed whereby it is relatively easy to acquire data on currents in submarine canyons. Savonius rotor current meters, explosive releases, and a free-fall system are utilized. The equipment, its deployment, and general conditions and problems are discussed, along with a brief description of analytical techniques.

Shepard, Francis P. (1975). "Progress of internal waves along submarine canyons." Marine Geology 19: 131-138.

Alternating up- and downcanyon currents with velocities to 50 cm/sec are found in submarine canyons. These alternations have patterns that usually can be matched between adjacent stations in the same canyon, even where separated by as much as 16 km. The matching of curves from adjacent stations is obtained by time shifts. In 20 of 23 comparisons, the patterns were best fitted by shifting so that a later time of arrival is indicated for the upcanyon station. This indicates that internal waves (mostly tidal in period) are advancing up the submarine canyons or, rarely, downcanyon. Because the data come from canyons off California, the East Coast of the U.S., and the Hawaiian Islands, and include depths to 3500 m, it is suggested that these canyon internal waves may be worldwide. The rates of advance of the internal waves lie between 25 and 50 cm/sec and average close to 40 cm/sec which is twice that found for internal waves on the continental shelf off San Diego. One might expect faster rates in canyons where the waves are moving into constricted areas as compared with advancing across the open continental shelf. The exceptional three downcanyon advances appear to be the result of unusual canyon bathymetry, perhaps combined with unusual tides. One of three downcanyon advances is from two stations in La Jolla Canyon separated by two hundred meters. Here, six comparisons suggested upcanyon advance, and only the seventh, with a time difference of five minutes, suggested downcanyon. The downcanyon advance data is not substantial evidence for downcanyon advance of internal waves and the most reliable case for it may be explained by a source of energy coming into the canyon head, rather than into the canyon mouth.

Shepard, Francis P. (1975). "Submarine canyons of the Pacific." Sea Frontiers 21(1): 2-13.

Written at a general level, covering La Jolla and Scripps Canyon among some other canyons.

Normark, William R. (1974). Submarine canyons and fan valleys; factors affecting growth patterns of deep-sea fans. IN: Modern and Ancient Geosynclinal Sedimentation; Submarine canyon and fan deposits. Society of Economic Paleontologists and Mineralogists, Special Publication. 19: 56-68.

Shepard, Francis P., Neil F. Marshall and Patrick A. McLoughlin (1974). "Currents in submarine canyons." Deep-Sea Research 21(9): 691-706.

Earlier work indicated that currents move alternately up and down the floors of canyons with greater average speeds and longer duration downcanyon. Later work shows roughly synchronous movements up to at least thirtyfour meters above canyon floors. The speeds decrease somewhat with height above the canyon floors and

upcanyon flows are more significant. The patterns of up- and downcanyon flow at adjacent stations usually can be matched, indicating that the currents are related to internal waves. Crosscanyon flow occurs, particularly during periods of strong crosscanyon winds and usually has a definite sequence of repetition related to the tidal cycle. During storms with strong onshore winds, there are violent downcanyon flows that have carried current meters with them and eroded the floors. Data from La Jolla Canyon is used along with other canyons.

Shepard, Francis P., Neil F. Marshall and Patrick A. McLoughlin (1974). ""Internal waves" advancing along submarine canyons." Science 183: 195-198.

Patterns of alternating up- and downcanyon currents have been traced along the axes of California canyons. The patterns arrive later at stations nearer the heads of coastal canyons. The propagation speeds of these patterns were estimated as 25-88 centimeters per second. Internal waves the the probable explanation. The current meter measurements in La Jolla Canyon at 167 and 206 meters were separated by only two hundred meters. The peaks in all but one out of seven cases were definitely displaced so that the waves were arriving later at the shallower station. Figure 16 of Shepard and Marshall 1973 indicated the opposite was true but a re-examination of original data showed that the two stations had been erroneously labeled. The average displacement was ten minutes and the propagation was thirty-three centimeters per second. The landward propagation speed of internal waves off Mission Bay is about twenty-two centimeters per second which suggests that internal waves advance faster up canyons. The faster rate may be due to the constriction of internal waves as they move into the narrow confines of canyons. A rather close relationship in the direction of flow patterns at various heights above canyon floors up to thirty-four meters has been established. At greater heights above canyon floors, the flows may be reversed in direction compared to those nearer the bottom. The authors attempted and failed to match the patterns between 78 and 167 meters in the axis of La Jolla Canyon. This may indicate either that internal waves do not propagate into the heads of canyons or that reflecting internal waves near the canyon heads may complicate the patterns sufficiently that they cannot be recognized.

Drake, David E. and Donn S. Gorsline (1973). "Distribution and transport of suspended particulate matter in Hueneme, Redondo, Newport, and La Jolla Submarine Canyons." Geological Society of America Bulletin 84(12): 3949-3968.

Studies of the distribution of suspended particulate matter in the waters over four Southern California canyons (one of which is La Jolla Canyon) were combined with analyses of recordings of canyon floor currents to evaluate the influence of canyons on the seaward dispersal of fine, terrigenous sediment. Suspended sediment concentrations and composition over the mainland shelf in fall and winter are controlled principally by

terrigenous-sediment supply. Consequently, particle concentrations at all levels generally increased toward the coast. The vertical distribution of suspended particulate matter was influenced strongly by the density structure of the water column on the shelf and slope, and sharply bounded, midwater turbidity maxima were well developed over the shelf where sediment supply is comparatively large. Nepheloid layers were present and ranged from a few meters to greater than two hundred meters in thickness with peak particle concentrations of five to seven milligrams per liter over the inner shelf and within the steep-walled, headward portions of each canyon. The slow, net downcanyon water transport may be explained in part by the mechanism of turbid layer flow.

Gibson, Daniel K. and Victor C. Anderson (1973). Sea-floor soil mechanics and trafficability measurements with the tracked vehicle "RUM". Marine Science Volume 2. Deep-sea sediments: physical and mechanical properties. Symposium on Physical and Engineering Properties of Deep-Sea Sediments, Airlie House, Virginia, Plenum House : New York. pp. 347-366.

Shepard, Francis P. (1973). Submarine geology. New York: Harper & Row.

Sea floor valleys are differentiated into submarine canyons (steep-walled, sinuous valleys, with V-shaped cross sections, axes sloping outward as continuously as river-cut land canyons, and relief comparable to land canyons with tributaries and with rock outcrops on walls), delta-front troughs, fan valleys, slope gullies, fault valleys, shelf valleys, and deep-sea channels. La Jolla and Scripps Canyons are physically described on pages 306-312 and a graph of current measurements for La Jolla Canyon is on page 332. Theories of submarine canyon origin due to single causes (i.e. the subaerial river-cut theory) are discredited in favor of combinations of processes (slides, slumps, currents). Several processes are both excavating and maintaining previously excavated canyons. Deposition either on the shelves or on the continental slopes is increasing the total wall heights of the canyons. A combined downcutting and upbuilding hypothesis provides a long period of time for the formation of huge canyons. There are old filled canyons lying below the floor of present canyons and canyon cutting may have alternated with fill at different episodes.

Shepard, Francis P. and Neil F. Marshall (1973). "Storm-generated current in La Jolla Submarine Canyon, California." Marine Geology 15(1): M19-M24.

Two current meters were operating in La Jolla Canyon at the 200 meter depth during a period of high seas and onshore winds up to 62 kilometers per hour (34 knots). The current meters were two and meters above the bottom. A relatively strong downcanyon flow occurred a few hours after the highest recorded wind velocities. The

records show a downcanyon speed up to fifty centimeters per second, considerably higher than any of the numerous earlier measurements. The record may provide evidence of the initial stages of a turbidity current that had built up gradually as the result of the surf beat induced by the strong onshore wind. After some lag, the heavy surf and powerful onshore wind probably developed a downcanyon flow as the result of piling up of water along the shore with a return underflow that may have stirred up enough sediment to produce a turbidity current.

Shepard, Francis P. and Neil F. Marshall (1973). "Currents along floors of submarine canyons." American Association of Petroleum Geologists Bulletin 57(2): 244-264.

Recordings of currents along the floors of submarine canyons off California and Baja California have provided insight into the nature of their movements. The records indicate that currents of less than 50 cm/sec alternate between upcanyon and downcanyon directions at periods ranging from about 20 minutes to more than 12 hours. In general, the longer periods, some of them related to tides, are found at the deeper stations (more than 250 meters), but shorter periods, probably related to internal waves, predominate at the shallower stations. In all but four of the 45 recordings in canyons, the net movement was found to be downcanyon. The predominant downcanyon net movement is in agreement with the finding of the steep side of ripple marks in a downcanyon direction in many bottom photographs and as reported by observers. Velocities usually are higher in downcanyon flows and the duration of flow usually is longer. These currents have sufficient velocity during the peaks of many flows to transport sand in appreciable quantities down the canyon axes. Velocities are at least as high at the deep as at the shallow stations in the same canyon. For the stations in La Jolla Canyon at 206 meters (14 records) and at 167 meters (8 records), the average length of upcanyon flow for each lowering is remarkably consistent - from 62 to 81 minutes and 61 to 80 minutes, respectively. The averages for downcanyon flow are much more variable for both stations. In La Jolla Canyon, the average length of downcanyon flows consistently increases with depth, but the upcanyon flows average about the same for all stations between 45 and 205 meters. However there was a remarkable increase in both downcanyon- and upcanyon-flow periods at the 375 meter stations. A record from La Jolla Canyon at 206 meters shows peaks of upcanyon flows close to times of low tides and peaks of downcanyon flows close to high tides. Variation in wind and wave conditions appears to have little if any effect on canyon currents except during major storms. Fragmentary evidence indicates that more powerful currents operate at rare intervals along the canyons. CORRECTION FROM Shepard, Marshall, and McLoughlin, 1974: The current meter measurements in La Jolla Canyon at 167 and 206 meters were separated by only two hundred meters. The peaks in all but one out of seven cases were definitely displaced so that the waves were arriving later at the shallower station. Figure 16 of Shepard and Marshall 1973 indicated the opposite was true but a re-examination of original data showed that the two stations had been erroneously labeled. The average displacement was ten minutes and the propagation was thirty-three centimeters per second.

McCarthy, James J. and Daniel Kamykowski (1972). "Urea and other nitrogenous nutrients in La Jolla Bay during February, March, and April 1970." Fishery Bulletin 70(4): 1261-1274.

Samples collected from three stations in La Jolla Bay twice weekly for 2 1/2 months were analyzed for nitrate, nitrite, ammonium, and urea in addition to other chemical, physical, and biological parameters. One station was on the south slope of La Jolla Canyon offshore La Jolla Cove, a second station was on the south edge of Scrips Canyon straight out from La Jolla Cove, and a third station was north of Scripps Canyon further offshore. On the basis of an infestation of blue sharks (Prionace glauca), periods before, during, and after the infestation were defined. Statistical analyses indicated that: 1) Urea concentrations were highest during the period of shark infestation. 2) There was strong positive correlation between phaeo-pigment/chlorophyll ratios and ammonium concentrations during the infestation but none between the pigment ratios and either the ammonium concentrations for the other two periods or the urea concentrations for any of the three periods. 3) There was no correlation between ammonium and urea concentrations before, a strong positive correlation during, and no correlation after the shark infestation. 4) Urea was the only nitrogenous nutrient for which the concentrations above and below the thermocline were not different. 5) Comparisons between two stations 1.5 km distant indicate that on a horizontal scale, the patch structure for urea is smaller than that of the other nitrogenous nutrients although the median urea concentration in the water column was not different at the two stations. The temporal similarity and the more complex patch structure for urea (as seen in 4 and 5 above) suggest that the blue sharks were responsible for the higher urea concentrations during the infestation. Although the median ammonium concentrations before and during the infestation were not different, the strong positive correlation between ammonium and urea concentrations during the infestation hint that the sources or rates of supply and utilization for both nutrients may have been closely related. The strong positive correlation between phaeo-pigment/chlorophyll ratios and ammonium concentrations during the infestation may imply that the source of ammonium was herbivore zooplankton excretion.

Moore, George W. (1972). "Offshore extension of the Rose Canyon Fault, San Diego, California." U.S. Geological Survey Professional Paper 800-C: C113-C116.

Has tectonic map of the sea floor northwest of La Jolla showing the offshore extension of the Rose Canyon Fault. Doesn't have bathymetry overlaid so one cannot tell exactly where it crosses La Jolla and Scripps Canyons unless the fault line is overlaid on a bathymetric map.

Noorany, Iraj and Robert A. Zinser (1972). Engineering properties of sea floor sediments from La Jolla canyon. Proceedings of the 13th Coastal Engineering Conference. 13th Coastal Engineering Conference, Vancouver, BC, American Society of Civil Eng. pp. 1559-1570.

Reserve, University of California San Diego. Dawson Los Monos Canyon (1972). Dawson Los Monos Canyon Reserve, Elliott Chaparral Reserve, Kendall-Frost Mission Bay Marsh Reserve, Scripps Shoreline-Underwater Reserve. University of California. 1972.

Shepard, Francis P. (1972). "Submarine canyons." Earth-Science Reviews 8: 1-12.

Discusses the nature and origin of submarine canyons. Mentions Scripps and La Jolla Canyon submersible dives with Cousteau's Soucoupe and Deep Star respectively. Cites observations of radical changes in the canyon bottom between dives. Includes Dill's 1964 diagrammatic profile of Scripps Canyon showing overhanging walls, smooth surfaces due to sediment creep, and irregular surfaces due to bioerosion.

Palmer, Harold D. (1971). Observations on the erosion of submarine outcrops, La Jolla submarine canyon, California. Abstracts with Programs, Annual Meetings, The Geological Society of America. Geological Society of America, 1971 Annual Meetings, Washington DC, Geological Society of America, Boulder, Colorado. pp. 666.

Submersible observations within the sinuous central segment of La Jolla Canyon provide spectacular examples of erosion at two deep outcrops. The first dive revealed extensive destruction through bioerosion of siltstone members exposed at a depth of 300-320 meters. Burrowing and grazing activity has led to slumping and spalling where cavities are clustered, intersect, or parallel the face of the outcrop. A rapid rate of erosion is indicated by the contrast in coloration between outcrop and scar surfaces and by sharp, jagged edges at the margins of such features. A second dive to a depth of 445 meters on the outside wall of a right-angle bend in the canyon axis revealed an undercut extending 23 meters deep beneath the vertical canyon wall. A well-established encrusting fauna reaching to the canyon floor indicates that abrasive high velocity currents have not occurred at this site for at least six months. The depth of this feature and the structural history of the region require that the process responsible for such erosion take place on the sea floor. Sediment samples from the fan and fan-valley well below this portion of the canyon reveal coarse deposits lacking features typical of turbidites, yet indicative of high velocity submarine currents. It is concluded that the undercut is a relict erosional feature remaining from a previous (Pleistocene) period when runoff producing the latest rapid rise in sea level must have generated "submarine floods" charged with coarse detritus.

Rees, Anthony I. (1971). "The magnetic fabric of a sedimentary rock deposited on a slope." Journal of Sedimentary Petrology 41(1): 307-309.

The magnetic fabric of a convoluted sandstone is simple despite the complex deformation of the sedimentary structures. This is thought to be due to local fluidization of the sediment during deformation.

Scanland, Thomas B. (1971). Effects of predation on epifaunal assemblages in a submarine canyon. PhD dissertation, Scripps Institution of Oceanography, University of California San Diego.

Shepard, Francis P. and Neil F. Marshall (1971). Normal sea-floor currents in submarine canyons. Abstracts with Programs, Geological Society of America, Annual Meetings. Geological Society of America, 1971 Annual Meetings, Washington DC, Geological Society of America, Boulder, Colorado. pp. 701.

Thirty-seven canyon floor current-meter records of two- to five-day duration provide convincing evidence of the patterns of canyon bottom currents. At depths of 45 to 375 meters, currents flow almost continuously, alternating between upcanyon and downcanyon with a net downcanyon. Periods of downcanyon flow are longer and average velocities are greater than those of upcanyon. In La Jolla Canyon and San Lucas Canyon (Baja California), directions of reversals are longer at the deeper stations. Velocities are often highest shortly after the current reverses. The currents are greater than eighteen centimeters per second in two percent of downcanyon flows and in 0.5 percent of upcanyon flows. Sand-size sediment is moved in a downcanyon direction by these currents. No currents greater than 35 centimeters per second were recorded, but such currents occur occasionally curing onshore storms. Simultaneous records at several canyon depths show times of current reversals are rarely the same at adjacent stations, suggesting an eddy type of circulation, probably related to internal waves with small tidal influence. In San Lucas Canyon, currents were strongest at the greatest depth, 328 meters, in agreement with coarsening sediments, but no rule could be developed a the five stations in La Jolla. Observations form diving vehicle descents and bottom photographs suggest that there are areas along the axes of canyons where currents are stronger than in bordering areas allowing the development of ripple marks.

Warme, John E., Thomas B. Scanland and Neil F. Marshall (1971). "Bioerosion, role of bivalves, polychaetes and other marine invertebrates, Observations in Scripps Canyon." Science 173(4002): 1127-1129.

Warme, John E., Thomas B. Scanland and Neil F. Marshall (1971). "Submarine canyon erosion: contribution of marine rock burrowers." Science 173(4002): 1127-1129.

Rock samples from Scripps Canyon indicate that physical and chemical weathering and erosion are relatively insignificant compared with bioerosion. Discoloration by chemical weathering commonly extends less than one centimeter from surfaces exposed to the sea, and several freshly collected rock samples were completely dry inside when broken open. In contrast, biological penetration extends several decimeters into the rocks. Rocks of the canyon rim and upper walls are intensely burrowed by marine invertebrates and large fragments of fallen rock are bounded by burrows. Important excavators are bivalves, polychaetes, and sipuncoloids whose activities results in a network of passageways and eventual rock disintegration. From the probably life spans of the burrowers and from the high proportion of burrows occupied by live animals, it is estimated that the average attrition of rock surfaces ranges from two to ten millimeters per year.

ZoBell, Claude E. (1971). "Drift seaweeds on San Diego County beaches." Beihefte zur Nova Hedwigia 32: 269-314.

Studies the quantity, kinds, and fate of drift seaweeds occurring along the San Diego County coast, including the cause of the occurrence and disappearance of drift seaweeds on the beaches. Fifteen of the observational stations were along La Jolla Shores beach from the Scripps Pier south. States that scuba divers have estimated that the total volume of moribund seaweeds slowly drifting seaward on the seafloor and in nearby submarine canyons is from ten to one hundred times as great as the volume of beached seaweeds.

Grigg, Richard W. (1970). Ecology and population dynamics of the gorgonians, Muricea californica and Muricea fruticosa: Coelenterata: Anthozoa. PhD dissertation, Scripps Institution of Oceanography, University of California San Diego.

The ecology and population dynamics of the gorgonian sea-fan corals, Muricea californica and Muricea fruticosa were investigated in order to discover what factors determine their distribution and abundance. Gorgonians were studied at several sites in La Jolla and one in Del Mar; transplantation experiments into La Jolla and Scripps Canyons were also conducted. In both species, the sexes are separate. Life cycles goes from polyp to egg to planula larva to polyp. Fertilization is probably internal, zygotes being discharged into seawater where they develop into free swimming planulae. The reproductive cycle is annual. Spawning takes place over several months beginning shortly after the maximum mean monthly temperature at depths were populations occur, a value above about fourteen degrees C being necessary for successful reproduction. Deeper populations spawn progressively later in the year extending the breeding season

of the entire population from two to 4-5 months. The planktonic life for most larvae lasts less than thirty days. Sexual maturity of M. californica and M. fruticosa is reached at ages of about five and ten years, respectively. Maximum ages of the two species are about twenty and fifty years, respectively. Both contain annual growth rings in their axial skeletons. The two species occur together over a vertical depth range of three to thirty meters. They orient at right angles to surge suggesting that the dominant movement of water is due to swell-induced surge. Fan-shaped gorgonians generally orient at right angles to current and are useful as indicators of the direction of average dominant water motion. The patterns of distribution and abundance at the shallow boundary suggests that the species here are primarily limited by space. At shallow depths less than three meters on wave-exposed coastlines, colonies are probably torn away by wave action or unable to survive the abrasive effects of sediment stirred up by turbulence. In order to determine depth tolerances, colonies were transplanted to greater depths in Scripps and La Jolla Canyons. After four months in South Branch of Scripps Canyon, all colonies below thirty meters were either heavily clogged with sediment and covered with white mucus or completely dead. These colonies were all placed at least five meters below the canyon rim on small outcropping ledges. The only transplants that survived were placed on the rim of the canyon at 27 meters where currents were generally less than five centimeters per second. In Cod Hole of La Jolla Canyon, colonies were transplanted to depths ranging between 33 and 38 meters. After 2.5 months, all colonies were alive. After 7.5 months, eleven of the original nineteen were gone, having apparently washed into the canyon. The remaining colonies, all M. californica, attached to larger stones were alive and growth had taken place on four of them. Currents were estimated to be about ten centimeters per second. Since some transplanted colonies can survive and grow below their normal depth limit, the lower depth limit for larval settlement probably results from lack of settlement. Low temperature may inhibit settlement while sediment-covered substrates may physically prevent settlement or cause larval avoidance. Larvae probably postpone settlement until suitable conditions and substrates are found. Natural selection would favor larval behavior that increased the probability of settling within the adult depth range. Reduced reproductive success may be caused by low temperature. The mean densities in number per square meter near the optimum depth of M. californica and M. fruticosa ranged from 0.62 to 7.90, and from 0.10 to 2.35 respectively. M. californica was always three to twentyfive times more abundant than M. fruticosa. Differences in abundance appear to be related to differences in rates of recruitment and longevity. Space appears to regulate recruitment in areas where substrates are fully occupied. The co-occurrence of both species in the same habitat is possible because competition between them for space and food is a rare event. Diet consists primarily of shelled larval organisms. Also discusses briefly the zoanthid Parazoanthus lucificum which partially overgrows M. californica but does not grow on M. fruticosa [CE Cutress and WE Pequegnat. 1960. Three new Zoantharia from California. Pac. Scil, 14(2):89-100].

Hamilton, N. and Anthony I. Rees (1970). "Magnetic fabric of sediments from the shelf at La Jolla (California)." Marine Geology 9(2): M6-M11.

The magnetic fabric is described of seven oriented box cores taken in water depths less than 100 m. All are fine sands and except one, a relict beach sediment, all appear to have been in sedimentary equilibrium with present conditions. They show signs of burrowing. The present magnetic fabric of all samples show signs of disturbance. Four of the seven retain sufficient primary fabric for a current direction to be estimated. There is evidence that the fabric disturbance is a result of the organic activity.

Inman, Douglas L. (1970). "Strong currents in submarine canyons." American Geophysical Union Transactions 51(4): 319 (abstract).

On two occasions, recorded currents up to 180 cm/sec (3.6 knots) prior to the breaking of a wire connected with the current meter in the shallow head of Scripps Canyon. Both times there was a strong onshore wind and large surf. Explained as the piling up of water along the shore and downcanyon pulses occurred as a result of surf beat.

Normark, William R. (1970). "Growth patterns of deep-sea fans." American Association of Petroleum Geologists Bulletin 54(11).

Palmer, Harold D. (1970). Submarine geography off Southern California. Los Angeles: Lorrin L Morrison.

Reprinted, with additional text and illustrations, from JOURNAL OF THE WEST 4(1), January 1965. General discussion with nothing specific on the local canyons; has Dill's picture of scuba diver at head of Scripps Canyon at 110 feet.

Piper, D.J.W. (1970). "Transport and deposition of Holocene sediment on La Jolla deep sea fan, California." Marine Geology 8(3-4): 211-227.

Near-surface sediments on La Jolla Fan have been studies using over one hundred cores, mostly sixty centimeter long box cores. Sediment distribution on the Fan is apparently related to processes acting along the prominent fan valley, which cuts deeply into Pleistocene sediments. The Holocene sediments in the fan valley consist of sands with some interbedding muds. A few of these muds are in thin beds in which the low sand content is graded. All the other muds are bioturbated. On the open fan away from the fan valley, sands are thinner and rarer. Sedimentary structures within the sands suggest they were deposited from relatively powerful currents, of gradually declining competence, carrying large amounts of sediment in suspension. These are thought to be turbidity currents. Much of the mud also appears to have been deposited from turbidity currents.

The Holocene sediments on the fan are about two meters thick, indicating that about ninety percent of the sediment being supplied to La Jolla Canyon is bypassing the fan.

Arthur, Robert S. (1969). "Variation in sea temperature off La Jolla." Journal of Geophysical Research, Oceans 65(12): 4081-4086.

Hour-to-hour and seasonal changes in temperature were measured by bathythermograph at a station 2.3 kilometers offshore on the axis of the La Jolla Canyon, where the depth was about 300 meters, for 26 days between 1 August 1957 and 31 March 1959. The temperature-depth traces for 21 series, each extending over 6 to 9 hours, show important hour-to-hour variations at all seasons as a result of internal waves. The range of vertical movement of three isotherms (12, 16, 20 degres C) is graphed and an extreme occurred on 18 November 1958, when the depth of the 12 degree C isotherm ranged from 63 to 117 meters. The location of the station over a submarine canyon raises the question whether the observed temperature variations are representative. Internal wave activity in much more shallow water close to shore has been shown to be similar with or without the presence of a canyon. It is believed that the observed variations are representative of the area off the California coast. Longer-term variations result from horizontal and vertical (upwelling) advection as well as local heating and cooling.

Dill, Robert F. (1969). "Earthquake effects on fill of Scripps Submarine Canyon." Geological Society of America Bulletin 80(2): 321-328.

Observations in the heads of Scripps and La Jolla Submarine Canyons have shown that three strong earthquakes (5, 5. 8, and 6. 3 on the Richter scale) did not trigger failure in marginally stable marine sediments. In situ density measurements compared with laboratory tests of canyon sediments show that fill accumulating under nearshore environmental conditions is near its critical density and will neither expand nor contract when stressed. Sands with these properties cannot be considered to be metastable or expected to fail by spontaneous liquefaction. Movements of sandy sediment from the canyon head into deep water have not been by earthquake-triggered turbidity currents but by other observable mass-movement processes.

Isaacs, John D. and R. Shutts (1969). Deep sea cine camera - film. California Cooperative Oceanic Fisheries Investigations: Annual Conference, Cambria, California. pp. 29.

Film presentation of an experimental deep sea cine camera system for use as a tool to study benthic life. Deployment was by un-manned free vehicle using timed releases and sequential triggering circuits. Several studies of bottom life were photographed at 1,600 feet in the La Jolla Canyon and 4,000 feet in the San Diego Trough.

Normark, William R. (1969). "Erosional deep sea fan valleys." Geological Society of America, Rocky Mountain Section, Abstracts: 59 (abstract).

Normark, William R. and D.J.W. Piper (1969). "Deep-sea fan-valleys, past and present." Geological Society of America Bulletin 80: 1859-1866.

Piper, D.J.W. and Neil F. Marshall (1969). "Bioturbation of Holocene sediments on La Jolla deep-sea fan, California." Journal Sed. Petrology 39(2): 601-606.

Schaefer, George V. (1969). "Geologic considerations for emplacement of Sealab II." MarineTechnology Soceity Journal 3(1): 25-28.

Field investigations of site location for Sealab II on the south flank of Scripps Canyon at a water depth of 205 ft. A sediment sampling program collected several samples that were analyzed for engineering properties, primarily sediment bearing capabilities and for standard grain size determinations. After emplacement of Sealab II, settling measurements of the laboratory made during the 45- day period it remained on the sea floor indicated all settling occurred soon after impact with the bottom.

Shepard, Francis P., Robert F. Dill and Ulrich Von Rad (1969). "Physiography and sedimentary processes of La Jolla submarine fan and Fan- Valley, California." American Association of Petroleum Geologists Bulletin 53(2): 390-420.

The depositional environments of La Jolla canyon, fan-valley, and fan are well known from closely spaced sounding lines, deep-diving vehicle observations, numerous undisturbed box cores, and continuous reflection profiles. The narrow rock-walled canyon changes seaward at 549 meters to a wider valley cut into the compact clayey sediments of a fan, and bordered by discontinuous leveelike embankments. The fan-valley merges gradually into the relatively flat floor of San Diego trough. Numerous dives into the fan-valley have shown precipitous walls along the outside of the bends of the winding channel. Slumping is taking place actively from these walls and large slump blocks of clay are common on the floor. Small scour depressions around isolated erratics suggest the erosive effect of relatively weak currents in some places but, for the most part, the muddy floor seems to have been little disturbed in recent years. Diagonal tension cracks cut the floor locally. Box cores show that most of the sediment deposited on the valley floor in the past few thousand years consists of poorly sorted clayey silt, underlain by discontinuous layers of well-sorted fine-grained sand with a few coarse sand grains,

gravel, and mud balls. Sand layers occur in 94% of the valley axis cores, of which 26% are graded; 59% have parallel laminations; and 41% have current-ripple cross-laminations. Sand layers are less common in the cores from levees and from the small discontinuous terraces along the sides of the fan-valley. Cores from the open fan have less and finer grained sand. In all these environments the sand shows no consistent or systematic grain-size variation with increasing water depths. Some of the coarsest sediments, including gravel and mud balls are found in sand farthest from shore and at the greatest depths. The character of the sand and the finding of shallow-water Foraminifera indicate the probability that sand has been carried from the coastal area along the valley axes and spilled over the levees onto the open fan. However, there is little evidence of recent high-velocity, high-density turbidity currents, because, in general, the covering mud layer is distinctly separated from the underlying sand deposits, and therefore does not suggest deposition at the terminus of a turbidity current. Also the discontinuous character of the sands and series of laminae with heavy mineral concentrations indicate introduction by a traction type of pulsating current, such as has been seen during vehicle dives, and also has been measured in the few available current-meter records. The locally precipitous fan-valley walls and outcrops of gravel, and the sand layers on the levees and open fan, may be the product of stronger currents that moved down the valley during earlier more pluvial periods, when greater quantities of sediment entered the canyon heads. Possible confirmation of this idea comes from the available C-14 dates in plant layers, which suggest that deposition in the past few thousand years may have been considerably slower than that indicated for the Pleistocene. The finer sediments may be largely the result of slow downslope movement of slightly higher density muddy waters coming from the coastal areas. Continuous reflection profiles have shown that the inner La Jolla fan has only a thin cover of unconsolidated sediments overlying the folded and faulted Miocene-Pliocene rocks. The outer fan and adjacent San Diego trough contain a thick section (more than 1,000 m) of Quaternary sediments with probable buried older channels and possible thick lenses of sand sediments.

Shepard, Francis P. and Neil F. Marshall (1969). "Currents in La Jolla and Scripps submarine canyons." Science 165(3889): 177-178.

Velocities up to thirty-four centimeters per second downcanyon were recorded near the floors of La Jolla and Scripps Canyons. Currents move alternately down- and upcanyon with variable periods with no discernible tidal relationship. Changes in flow from upcanyon to downcanyon are generally slow, but are much more rapid than are changes from downcanyon to upcanyon. All three- to six-day measurements show net current transport downcanyon. Many of the downcanyon currents of higher velocity correlate with ebbing tides. Many of the peaks clearly have a tidal cycle, although others are associated with changes of direction of short duration that are not related to the tide. Plots of the total movement or trajectory of currents near the floor of a canyon show a large residual in the downcanyon direction. Superimposed records of three current meters at 3.6 meters, 19 meters, and 34 meters above the bottom of La Jolla Canyon at

206 meters depth indicate a large net movement downcanyon near the floor. Slight net movement downcanyon occurred 19 meters above the bottom, and at 34 meters the movement was at first toward shore and then it reversed, so that a water particle would have had no net axial transport. As distance above the canyon bottom increases, net transport becomes more related to ordinary tide-influenced oceanic patterns. During 34 percent of the time recordings were made, flow was downcanyon; 42 percent of the time, flow was upcanyon. During the remaining 24 percent of the time, it was changing direction. Currents capable of eroding sand (over 18 cm/sec) make up 4.8 percent of all recorded flow time or 14.4 percent of downcanyon flow time. Erosive currents upcanyon occur, but they are negligible in number and duration. Net transport is always downcanyon since average downcanyon flow is 8.25 cm/sec, whereas average upcanyon flow is 1.85 cm/sec. Downcanyon flows last 47 minutes on the average, and upcanyon flows last for an average of 74 minutes. Other factors producing the currents probably include internal waves. There were several cases in which reversals in direction occurred at periods of about four hours which is a similar period to studies of internal waves at the US Navy platform off Mission Beach. Normal current velocities are capable of transporting considerable quantities of sand down the canyon axis. These observed currents are entirely different from powerful turbidity currents.

Warme, John E. (1969). "Marine borers in calcareous terrigenous rocks of the Pacific coast." American Zoologist 9(3): 765-774.

Rocks of the rim and upper walls of Scripps Submarine Canyon are intensely burrowed by marine invertebrates. Important excavators are bivalves, polychaetes, and sipunculoids whose activities culminate in a network of passageways and eventual disintegration of the rocks. In many localities erosion by animals is more important than erosion by physical and chemical processes.

Holden, John C. (1968). Brackish water ostracods from La Jolla submarine canyon 7200 (plus/minus) 500 years before present. Berkeley, CA: University of California Berkeley Museum of Paleontology.

Perissocytheridea meyerabichi in the Holocene offshore from San Diego, differing from living species, confirm lagoonal origin of cliff-forming strata in La Jolla Canyon on which Shepard and Dill (1966) determined the age from a C-14 date on a root. Five horizons, recollected at 10-ft intervals 27.5 to 16.0 m below sea level, were mostly barren; listed fossil assemblages show a few foraminifers and ostracodes at 27.5, 21.5 and 16.0 m intervals. Perissocytheridea, one of a few ostracodes restricted to brackish environments, is unknown today in likely southern California waters. The minus 16.0 horizon contained only P. meyerabichi, which represents almost half of the ostracode fauna at the root locality. This species has been observed from a Pleistocene outcrop of

the Bay Point Formation in Carmel Canyon, but not in the normal marine facies at the type locality.

Normark, William R., Michael S. Loughridge and Fred N. Spiess (1968). "Detailed channel morphology of the La Jolla submarine fan valley." Transactions, American Geophysical Union 49(1): 212 (abstract).

Rees, Anthony I., Ulrich von Rad and Francis P. Shepard (1968). "Magnetic fabric of sediments from the La Jolla submarine Canyon and Fan, California." Marine Geology 6(2): 145-178.

The results of measurements of the anisotropy of magnetic susceptibility of 24 box cores from the La Jolla Submarine Canyon and Fan are described and compared with magnetic fabrics produced under controlled conditions and with visible directional sedimentary structures. Many cores have a fabric similar to that produced during deposition from running water in the laboratory, and it is concluded that most of the sediment had a fabric of this type immediately after deposition. Most of the samples from the upper canyon have a 'primary' magnetic fabric, characterized by a near horizontal magnetic foliation plane, susceptibility maxima well grouped in this plane and approximately parallel to the canyon axis, and q values ranging about 0.4. The sediments from the fan-valley and from the fan show, at least, traces of a similar type of primary fabric. In general, maximum susceptibility axes trend approximately parallel to the fan-valley axis and to the crests of the adjacent levees. The effects of two types of deformation were distinguished: the first of these, recognized by a tendency of the susceptibility minima to be streaked out toward the horizontal and by variable q values, is explained as being the result of forces tangential to the bedding plane, possibly the component of gravity acting tangentially to the side slopes of the channel. The second type of deformation, reflected in the magnetic fabric, by low total anisotropy, high q values, and scattered directions of susceptibility axes, is thought to be due to the randomizing action of burrowing organisms.

Shepard, Francis P. and Edwin C. Buffington (1968). "La Jolla submarine fan-valley." Marine Geology 6(2): 107-143.

The submarine fan built into San Diego Trough off La Jolla, is creased by a steep-sided valley that "hooks" left, as do most fan-valleys off the western United States. Close-spaced, well-controlled sounding lines have allowed detailed contouring of the feature. Somewhat complex natural levees are quite continuous along the right bank of the valley but poorly developed along the left, except along the outer third of the valley. Terraces are well developed in the central portion of the valley adjacent to the inner channel. They

occur intermittently and at variable heights above the floor in the middle portion and are inconspicuous along the outer valley. A landslide origin of most of the terraces seems probable. The La Jolla Fan-Valley differs from many others in lacking distinct distributaries, although remnants may exist along the outer part where the valley merges into San Diego Trough at about 600 fathoms. The precipitous walls on the outer bends of the fan-valley along with the clean sands found under a thin mud layer in the channel are indications of active erosion still intermittently in progress.

von Rad, Ulrich (1968). "Comparison of sedimentation in the Bavarian flysch (Cretaceous) and Recent San Diego Trough (California)." Journal of Sedimentary Petrology 38(4): 1120-1154.

Buffington, E. C. D., D. G. Moore, R. F. Dill and J. W. Vernon (1967). "From shore to abyss: nearshore transport, slope deposition and erosion, canyon transport, and deep-basin sedimentation." The American Association of Petroleum Geologists Bulletin 51(3, part 1): 456-.

Clarke, Thomas A., Arthur O. Flechsig and Richard W. Grigg (1967). "Ecological studies dueing Project Sealab II." Science 157(3795): 1381-1389.

Reports on animal community surrounding Sealab II and effects of Sealab II's presence on those animals. Sealab II attracted rocky-bottom and mid-water organisms. The increase in biomass of resident fishes was almost thirty-five times that of the normal sand-bottom community, an effect similar to artificial reefs. Although the site area was generally typical of local sandy bottoms, the proximity of Scripps Canyon may have influenced the types and numbers of organisms present, especially as many sand-bottom organisms are locally more abundant along the canyon edges than on the open sand.

Clutter, Robert I. (1967). "Zonation of nearshore mysids." Ecology 48(2): 200-208.

Between the shore and seventeen meters depth, over sand bottom inshore and between La Jolla and Scripps Canyons, five species of hypopelagic mysids and four species of benthic mysids occurred in bathymetric zones roughly parallel with the shore. The possible causes and function of zonation of the numerically dominant pelagic species were examined. The information suggests that the zonation may have developed as observed mainly in response to the pattern of availability of food that was imposed by the nearshore circulation system, and that competitive exclusion of other pelagic specied occurred. The zonation may provide a situation wherein population control can be effected by changes in reproduction rate.

Dill, Robert F. (1967). "Processes of submarine erosion in La Jolla fan valley and their relation to sediment distribution patterns." American Association of Petroleum Geologists Bulletin 51(3): 461 (abstract).

Shepard, Francis P. (1967). The earth beneath the sea. Baltimore: Johns Hopkins Press.

Author states in preface that this book is a popularization of his book entitled Submarine Geology avoiding discussion of complicated and technical aspects. On pages 116-120, Scripps and La Jolla Canyons are mentioned in a chapter entitled "Canyons of the Sea Floor." Physically describes the canyon and includes the standard map of both canyons, a picture of a model of Sumner Branch, a picture of the sandy floor and vertical wall of Scripps Canyon at 460 feet (taken from Cousteau's Diving Saucer by Inman), and the two halves of a core showing sand layers alternating with deep-water clay layers taken from La Jolla Canyon at a depth of 2,100 feet. Describes scuba diving observations and Diving Saucer observations. From the Diving Saucer below the juncture of North and Sumner Branches of Scripps Canyons, they observed vertical walls, overhanging ledges, and narrow gorges. The axis of the canyon had an irregular steplike descent with vertical drops interspaced with gentle slopes. Observed boulders that had fallen from the walls. Observed smoothed canyon walls with grooving which is explained by Robert Dill as the effect of creeping sediment bound with kelp and marine grass debris and containing many rocks that press against the walls as the sediment creeps downward under the influence of gravity. Below the juncture of Scripps and La Jolla Canyons, observed less precipitous walls. Describes bathyscaph Trieste observations of the La Jolla Canyon Fan Valley. The fan valley has some very precipitous walls, even as much as 75 degrees. The fan valley floor has a thin mud cover in most places but is directly underlain by sand and some gravel. Observed a series of cobbles along the valley floor. Terraces along the valley sides are due to landslides. Cores taken along the axes of the La Jolla and Scripps Canyons have yielded sand layers and some gravel at a variety of depths. In some cases, only sand was obtained, but in general sand alternated with layers of mud. The canyon sand is as free from mud as the sand along the beach inshore of the canyon. Sand also occurs on the floor of the Fan Valley and also in the San Diego Trough beyond the Fan Valley. On pages 136-137, author notes that the movement of sand along the La Jolla coast is sufficiently rapid to full the canyons completely within a few years but has watched the depth changes for more than thirty years and seen no net fill. The periodic landslides in the canyon heads after earthquakes and more commonly after and during periods of large waves clear the canyons. Author experienced an earthquake in 1949 while eating lunch in the patio of La Valencia Hotel and observed afterwards that the water had deepened as much as sixteen feet along one of their survey lines in a canyon head. A figure compares echo sounding lines in the head of Scripps Canyon, showing a considerable deepening between the two measurements.

Shepard, Francis P. (1967). "Submarine canyon origin: based on deep-diving vehicle and surface ship operations." Revue de Geographie Physique et Geologie Dynamique 9(5): 347-356.

Barnard, J. Laurens (1966). Submarine Canyons of Southern California, Part III, Systematics: Amphipoda. IN: Submarine Canyons of Southern California. Allan Hancock Pacific Expeditions. Los Angeles: University of Southern California Press. 27: 166.

Study of the amphipods in the thirteen Southern California submarine canyons studied (including La Jolla Canyon) . Reviews biology of the canyons and provides additional analysis beyond Hartman's 1963 analysis. In his introductory review of the biology of these submarine canyons, Barnard discusses the earlier suggestion (Emery & Hulsemann, 1963) that Capitella capitata is an indicator of undersea leakage from emergent sweet-water aquifers in submarine canyons. C. capitata is tolerant not only of brackish waters but of polluted conditions in waters of normal salinity and thus may be an indicator of natural putrefaction. It lives in high densities in the inner harbor of Los Angeles in waters of normal salinity but low disolved oxygen. Its occurrence in some canyon samples may be related to high contents of organic matter in the sediments that are restrictive to other metazoans. Capitella appears to tolerate wide ranges of physical conditions that are restrictive to most organisms but apparently is seldom found with other animals. In the depth-sediment scheme, the Capitella samples are grouped in the coarse sediment range, indicating the presence of percolating water that must leak through coarse sediments. In bays and harbors Capitella inhabits fine-grained sediments.

Carpenter, M. Scott and James R. Stewart (1966). Some safety aspects of outer and inner space. IN: 1966 National Safety Congress, Aerospace Section: 18-25.

On page 22, Stewart briefly mentions the difficulty of manned submersible diving into the canyon near the Sea Lab II site, specifically using the manipulator arm.

Dill, Robert F. (1966). Erosion in the head of La Jolla submarine canyon. Osaka City University, Journal of Geosciences. Sea level changes and crustal movements of the Pacific during the Pliocene and post-Pliocene time, Pacific Science Congress, 11th, Tokyo, 1966, Symposium 19. pp. 105 (abstract).

Dill, Robert F. (1966). Erosion in the head of La Jolla submarine canyon. Abstracts of papers related with oceanography, Proceedings of the 11th Pacific Science Congress. 11th Pacific Science Congress, Tokyo, Sci. Council Japan [Sec. 9]. pp. 62-63.

Schultz, George A. (1966). Submarine Canyons of Southern California, Part III, Systematics: Isopoda. IN: Submarine Canyons of Southern California. Allan Hancock Pacific Expeditions. Los Angeles: University of Southern California Press. 27: 56.

For the thirteen Southern California submarine canyons studied (including La Jolla Canyon) , lists their isopods both by canyon and in systematic order.

Shepard, Francis P. and Robert F. Dill (1966). Submarine Canyons of the La Jolla, California Area. IN: Submarine Canyons and Other Sea Valleys. F. P. Shepard and R. F. Dill. Chicago: Rand McNally. Chapter 3: 31-68.

Descriptive overview of the canyon system. Summarizes previous research.

Wicklund, Robert (1966). "Sea Lab powerful attraction to fish." Underwater Naturalist 3(4): 23-25.

During the summer of 1965 large numbers of fishes were attracted by the U. S. Navy's Sea Lab, located at a depth of 205 feet near the edge of Scripps Submarine Canyon, 2000 yards west of the Scripps Pier. The fish population grew rapidly from a few scattered fish on the first day to an estimated 6500 fish by the 44th day. The attractive power of the structure was thought to be due to the lights which attracted planktonic life and small fish. Larger fish and a sea lion gathered to forage on these smaller forms.

Marine Physical Laboratory (1966). “MPL participation in SEALAB II.” SIO Reference 66-3. La Jolla, Calif.; Scripps Institution of Oceanography, 1966

Summarizes participation of Scripps Institution of Oceanography’s Marine Physical Laboratory in SEALAB II. Report includes results of the fine-grained, topographic site survey, details and experience with the Benthic Laboratory System, and a summary of shore communication center operations during the program.

Bouma, Arnold H. (1965). "Sedimentary characteristics of samples collected from submarine canyons." Marine Geology 3(4): 291-320.

A detailed study of sedimentary structures was made on oriented sediment cores collected in various submarine canyons off southern California and Baja California; X-ray radiography on vertical slices of cores was the primary technique employed. The few

primary sedimentary structures in the clayey shelf sediments in southern California are those caused by slumping and reworking by organisms. Sediments from the axis of canyons are coarse and show parallel and current-ripple lamination, and some small-scale graded bedding; slump phenomena and reworking by organisms are not common. Away from the axis, samples were finer grained and show fewer primary and more secondary structures. A sample from the apron of the La Jolla Fan Valley has a succession of sedimentary structures similar to the facies of ancient turbidites. Sediment transport is discussed, and it seems likely that it is not purely a mass movement.

Dill, Robert F. (1965). "Bathyscaph observations in the La Jolla submarine fan valley." Bulletin of the American Association of Petroleum Geologists 49(3): 338 (abstract).

Gorsline, Donn S., J.W. Vernon and A. Shiffman (1965). Processes of sand transport in the inner margins of the continental shelf. 39th Annual Meeting of the American Society of Paleont. and Minerol., New Orleans. pp. 63 (abstract).

Kirschenbaum, J. M. (1965). "45 days on the bottom of the ocean." Navy 8(10): 32-34.

Moore, David G. (1965). "The erosional channel wall in La Jolla Sea-Fan Valley seen from bathyscaph TRIESTE II." Bulletin of the Geological Society of America 76(3): 385-392.

Nearly horizontal beds of stiff cohesive clays alternating with cohesionless silts crop out along a steep wall of the channel in La Jolla Fan Valley in water depths of about 3,000 feet. These exposures are believed to be the result of lateral channel erosion by turbidity currents; this should result in periodic development of new channel routes. Once current erosion forms these steep walls of outcropping sediment layers, the sliding of clay blocks, local slumping, and the action of benthic organisms modify them. Recently active turbidity currents are believed to be of a much smaller scale than those responsible for the development of the large morphological features of the overall fan valley.

Shepard, Francis P. (1965). Submarine canyons explored by Cousteau's Diving Saucer. Submarine Geology and Geophysics, Proceedings of the Seventeenth Symposium of the Colston Research Society, University of Bristol, Butterworths: London. pp. 303-311.

Scripps and La Jolla canyons were explored to depths of 1,000 feet by the Cousteau diving saucer. Scripps Canyon is a narrow gorge about one mile long with three main tributaries coming into its head near the coast. Scripps Canyon is cut into

sedimentary Eocene rocks, including a large amount of conglomerate and some sandstone and mudstone as seen in the sea cliffs to the north. Scripps Canyon has precipitous, narrow, sometimes overhanging rocky walls nearly its entire length, with sections so narrow that the nine foot wide diving saucer cannot descend to the bottom. La Jolla Canyon is wider than Scripps Canyon and has at its head a series of gullies cut into Pleistocene alluvium and lagoonal formations; lower down, it cuts through Eocene and Cretaceous rocks. La Jolla Canyon has a wide bowl near the head, but a much narrower rock gorge with steep walls is entered at 400 feet. Scripps Canyon joins La Jolla Canyon at a depth of about 900 feet, and the two continue seaward as a rock-walled canyon to about 1,600 feet, where a fun valley cut into unconsolidated sediment is encountered. Both canyons have a series of steps along their axes, some with rock lips with a vertical drop of ten feet or more, whereas others have steep sediment-covered slopes a few feet high, suggestive of landslide scars. Radical changes were observed between some saucer dives, even within one week. Large blocks fall from the canyon walls and project from the sediment on the canyon floor, sometimes damming of the sediment moving down the canyon. Canyon walls have scoured and grooved surfaces under the overhanging walls, particularly in Scripps Canyon; active erosion is unquestionably taking place. Sediment on the floor at any one place may be swept clean and change character completely within a short period of time (weeks or months), that is, from organic debris to sand or mud and back again. Currents are variable and sometimes resulted in aborted saucer dives due to the inability of the saucer to make headway against them at 0.5 knots. Currents tend to move more down- than up-canyon and reversals were observed during the same dive. There were glimpses of moving sand and ripple-mark formation on the canyon floor during times of high currents.

Shepard, Francis P. (1965). "Diving saucer descents into submarine canyons." Transactions of the New York Academy of Sciences 27(3): 292-297.

The diving saucer built by Jacques Cousteau was used for underwater observations on the Scripps and La Jolla canyons. It has permitted close study of canyon walls and floors and of effects of weak currents flowing along the floors. Some erosion is noted in the inner canyons but it does not appear to have been caused by turbidity currents.

Shepard, Francis P. (1965). Effect of submarine valleys on water masses and currents. IN: Oceanography from space. Woods Hole Oceanographic Institution Reference. 65-10: 243.

Submarine valleys have an important effect on water masses and currents as demonstrated by the upwelling along the La Jolla canyons. These movements can be photographed from the air because of color changes or lines of foam.

Shepard, Francis P., Joseph R. Curray, Douglas L. Inman, E.A. Murray, Edward L. Winterer and Robert F. Dill (1965). "Saucer dives in La Jolla submarine canyons off La Jolla, California." Geological Society of America Special Paper 82: 182-183.

von Rad, Ulrich, Francis P. Shepard, A.M. Rosfelder and Robert F. Dill (1965). Origin of deepwater sands off La Jolla, California. Geological Society of America Annual Meeting, Kansas City, MO. pp. 177 (abstract).

Bouma, Arnold H. and Francis P. Shepard (1964). "Large rectangular cores from submarine canyons and fan valleys." American Association of Petroleum Geologists Bulletin 48(2): 225-231.

Box cores taken in submarine canyon and fan valley areas off La Jolla and Baja California, indicate that gravel is a common constituent under thin mud. The scarcity of graded bedding suggests slumping of sediment in addition to the work of turbidity currents. The box corer is described as a tool to combat problems of currents during sampling and to help orient the structure.

Buffington, Edwin C. (1964). "Structural control and precision bathymetry of La Jolla Submarine Canyon, California." Marine Geology 1(1): 44-58.

A bathymetric survey of La Jolla Submarine Canyon, California, utilizing an electronic positioning system and Precision Depth Recorder (PDR), has resulted in a large-scale chart considerably more detailed and accurate than hitherto possible. The topography revealed by this chart shows a series of depositional terraces and a sinuous channel on a transversely flat, seaward sloping canyon floor. Apparent offsets to the canyon axis are correlated with well established fault patterns ashore, suggesting structural control of the present canyon course.

Chamberlain, Theodore K. (1964). Mass transport of sediment in the heads of Scripps Submarine Canyon, California. IN: Papers in Marine Geology, Shepard Commemorative Volume. R. L. Miller. New York: Macmillan Company: 42-64.

Scripps Canyon branches into three major heads and numerous minor tributaries and chutes. The major branches are North, Sumner and South Branches; all three heads can be traced into the coastal cliffs as incised land canyons. The tributaries to these main branches enter from the onshore direction and have no continuing expression in the adjacent land topography. The largest tributary is named Intermediate Tributary along the eastern wall of Sumner Branch. The depth of the bedrock for two hundred positions at the

head of Scripps Canyon was determined. The bedrock slopes leading into the branches of Scripps Canyon are variable. The side slopes range from vertical or overhanging in the deeper parts of the heads to about twenty degrees at an axial depth of twenty meters. The axial slopes themselves, characteristically convex upward, are no more than two to five degrees in the trough-like depressions near the surf zone, but they increase to fifteen degrees at a depth of twenty meters and steepen rapidly to thirty degrees or more at depths of sixty meters. From the point of juncture of South and Sumner Branches the axial slope of the main canyon flattens, and the reminder of the canyon gradient assumes a concave upwards profile. The axial slopes of this outer portion of Scripps Canyon are on the order of five degrees. Scripps Canyon sand level fluctuations are shown for 1948 to 1960 showing eleven significant catastrophic deepenings. Because of the local submarine topography and the angle of wave approach, seaward-flowing rip currents develop over the heads of Scripps Canyon (SCh) when large volumes of water are driven onto the adjacent beaches. The result is that during local storms the large volumes of sand formerly deposited on the beaches and in the nearshore zone by alongshore currents are carried seaward and deposited in the SCh. During the storm of November 15-16 1958, 1000 cubic meters of sand were deposited in South Branch and probably another 3000 cubic meters in Sumner Branch. Although most of the sand was introduced from areas north of the canyon proper, it has been assumed based on observations of beach cuts that 1200 of these 4000 cubic meters were from erosion of the beach face at SCh. During periods of maximum sediment transport by rip currents, the sand deposits in SCH are rapidly prograded along the canyon axes into deep water. In a few days the face of this prograding sand unit may advance eight meters, and sediment thicknesses of up to three meters may be deposited. Sand slopes are also steepened, and the axial slopes may increase one to two degrees. These sand units, built out into the canyon heads by littoral currents, are sorted and transported to greater depths by the orbital motion of water associated with the passage of waves. The less dense and finer particles -particulate organic matter and mica - are transported the farthest and come to rest in depths of 20-25 meters. Approx one-tenth of the yearly sediment deposition in the canyon heads - ie 20,000 cubic meters - is organic detritus. This detritus is composed almost entirely of the remains of the large brown kelp Macrocystis pyrifera and the surf grass Phyllospadix torreyi. Brown algae and seagrasses account for 90-99 percent of the bulk of the detritus with relative proportions being 40 and 60 percent respectively. Minor amounts of other marine plants are found. The periodic loss of sediment from SCh is not due to erosion by waves and currents. Periods of strongest current and wave action were significantly related to periods of slope accretion in SCh. Canyon deepenings have been observed to occur a day or two apart, and once deepened, no significant additional loss of materials takes place. It appears that mass transport of sediment out of SCh is a catastrophic event, encompassing a few hours or days, and caused by slope-failure in which a certain critical value is exceeded, resulting in slope collapse and sediment transport. Earthquake shocks, differential vertical compaction of the various sedimentary facies, and lateral pressures built up by the rapid accumulation of sand in SCh and the resulting lateral compression of the seaward-lying organic detritus may all be causes of excess strains resulting in a catastrophic flow of sediment down the canyon axis. A reduction of shear strength by organic decomposition may be sufficient to allow shear

failure either within the detrital mat itself of between the organic mat and the bedrock surface; in either case the result would be a catastrophic loss of support for the upslope sand deposits and subsequent mass transport of material down the canyon axis. The total amount of nearshore sand captured yearly by Scripps Canyon is approximately equal to the total yearly littoral drift of sand down the coast. The most important erosional processes are those associated with gravitative transfer of material moving tens of thousands of cubic meters of sand per year down the canyon axes resulting in corrasion of the bed rock and abrasion of loose boulders and projecting ledges. The rock walls are rough and angular above the level of yearly sedimentary fill; below this level the bed rock is smooth and rounded. Boulders up to at least a meter in diameter are transported completely out of canyon heads. Undercutting of resistant ledges below the level of sedimentary fill is common. Many projecting ledges and knickpoints along the bottom of the canyon are well-rounded and polished. Currents and waves do not appear to have a direct effect upon the erosion of bedrock within the canyon. However wave motion does agitate sand deposits on the intercanyon ridges sufficiently that this sand spills into chutes along the canyon rims. In less than 60 meters water depth in Scripps Canyon, there is no evidence of the turbidity current process occurring. The youngest rocks outcropping in Scripps Canyon are Eocene sediments, which are found continually from the Cretaceous-Eocene contact at about 60-170 meters below water up to present sea level and as 110 meter sea cliffs above water. In La Jolla Canyon, Cretaceous and Eocene rocks are found on the walls below about forth meters depth; shallower than forty meters, La Jolla Canyon is cut into poorly consolidate Pleistocene alluvium. Scripps-La Jolla Canyon is younger than the Eocene Epoch, and at least the shoaler portions of La Jolla Canyon have been cut sometime during or subsequent to the deposition of the Pleistocene deposits through which they are incised. Calculating the age of Scripps-La Jolla Canyon based on the volume of sand in the broad alluvial fan suggests that sometime during the latter part of the Pliocene Epoch, it began to be incised into the formations of what is now the continental shelf.

Dill, Robert F. (1964). Contemporary Submarine Erosion In Scripps Submarine Canyon. Ph.D dissertation, Scripps Institution of Oceanography, University Of California, San Diego.

Dill, Robert F. (1964). Sedimentation and erosion in Scripps Submarine Canyon head. IN: Papers in Marine Geology, Shepard Commemorative Volume. R. L. Miller. New York: Macmillan Company: 23-41.

Reports observations made in Scripps Canyon on Dec 5, 1959, March 24, 1960 and Jan 1 to Mar 6, 1961. The detrital mat is composed of fine sand and silt interbedded and mixed with broken pieces of sea grass and kelp. The organic portion was decomposing, forming gas actively bubbling to the surface. Decomposition was associated with a strong hydrogen sulfide odor and immediately around the gas seeps are large white aureoles

caused by a powdery deposit on mat organic material. The hydrogen sulfide and blackened sediment around the gas seeps indicate a reduced state. The mat shrinks away in some places from the canyon wall possibly due to compaction; as the material decomposes and settles, the mat is gradually pulled away and down from the rock wall which was its original boundary. The canyon was initially formed subaerially and is now being modified considerably from the typical V-shape of nearby subaerial canyons by sand abrasion and sediment-mat movement. Sand chutes of various sizes cut into the rocky lip of the canyon and lead down to the sedimentary fill. They are filled with fine sand with very little broken kelp material. Where found, rock appears to be undergoing erosion by movement of sediment down sand chutes and through tributaries leading into the main axis of the canyon. The hour-glass shapes of several tributaries, the polished and smoothed irregularities of the rock walls, the movement and smoothing of irregularities of fallen blocks of bedrock, the eroded and truncated holes of marine boring organisms, and the lack of organisms in areas that are only periodically covered with sediment are evidence of sediment movement. Sediment movement leads to erosion of the rock walls through abrasion and plucking by the sediment mat as it moves slowly down the canyon like a glacier. The filling and rapid flushing by sand slides (one to two per year), and the slow movement of sedimentary material from the canyon heads in the form of an organic sediment mat cause erosion of Scripps Canyon's rock walls. The rapid refilling of the axes of tributaries by sand and organic material after flushings would seem to protect the underlying rock surfaces from turbidity-current erosion except during the brief period (one to two weeks) following flushing. Turbidity currents are not responsible for observed conditions but may be active further down the canyon where it empties upon the sedimentary fan in the San Diego Trough. Turbidity currents set up by divers do not appreciably erode sedimentary materials. The sedimentary slopes during the time of the first investigation were stable yet only one week later, all sedimentary fill was removed and bare rock was exposed. There appears to be submarine erosion in areas that are normally covered with sediment fill, and such an erosional process must take place while the canyon is filled with sediment. The grinding action of the sediment contained in the mat during its slow movement down slope as it consolidates is the proposed process. A fine brown organic layer, a few millimeters thick, was present on the sediment above the canyon lip during December 1959 and was reported to be dead diatomaceous debris. This deposit disperses when disturbed by the slightest current and must have been deposited by flocculation rather than a slow particle-by-particle settling. This organic material has been observed elsewhere in southern California during quiescent periods when no bottom currents were active.

Dill, Robert F. (1964). "Submarine erosion in the head of La Jolla Canyon." Bulletin of the Geological Society of America noted "in press" in 1966.

Dill, Robert F. (1964). "Contemporary erosion in the heads of submarine canyons." Geological Society of America Special Paper 76: 45 (abstract).

Hopkins, Thomas S. and Thomas B. Scanland (1964). "The host relations of a pinnotherid crab, Opisthopus transversus Rathbun (Crustacea: Decapoda)." Bulletin of the Southern California Academy of Sciences 63(3): 175-180.

The mottled pea crab Opisthopus transversus crabs inhabits sheltered spaces within many species of animals in a commensal relationship not harming the sea cucumber, including the intestines of the sweet potato sea cucumber Caudina arenicola (formerly Molpadia arenicola). The largest, most mature mottled pea crabs are the egg-bearing females, and they can be found in the intestine of Caudina arenicola. 24 Caudina arenicola were collected in La Jolla Canyon head for this study; another 28 were collected from Mission Bay. 17 of the 24 LJ Canyon sea cucumbers sheltered the pea crab Pinnixa barnharti, while 7 sheltered the mottled pea crab Opisthopus transfversus. The mottling of Opisthopus transversus can be dependent on the food and its pigment gathered by their host, since the crabs may feed on this gathered food. Sea cucumbers ingest mud rich in carotenoid pigments, and mottled pea crabs living within Caudina arenicola maintain a reddish brown and white color pattern, while those living within other hosts may have a paler color with less discernible mottling.

Moriarty, J.R. (1964). The use of oceanography in the solution of problems in a submarine archaeological site. IN: Papers in Marine Geology. R. L. Miller. New York: Macmillan: 511-522.

Indian mortars

Shepard, Francis P., Joseph R. Curray, Douglas L. Inman, Earl A. Murray, E.L. Winterer and Robert F. Dill. (1964). "Submarine geology by diving saucer." Science 145(3636): 1042-1046. September 4, 1964 1964.

Using the French two-man diving saucer, eight dives were made into the narrow rock Scripps and La Jolla submarine canyons and one to the nearby shelf and upper slope. Observations on the topography, currents, and sediment transport are reported.

Dill, Robert F. (1963). Features In the heads of submarine canyons--Narrative of underwater film. Developments in Sedimentology. 6th International Sedimentological Congress, Amsterdam and Antwerp. pp. 101-104.

This paper deals with creep of sediment and rapid flow of sand over the steeply sloping floor of some submarine canyons off California and Baja California. The sediment

motion apparently causes scour of the canyon floor and walls. The phenomena were directly observed and filmed by geologists diving in the upper parts of the canyons.

Emery, K.O. and Jobst Hulsemann (1963). Submarine Canyons of Southern California, Part I, Topography, Water, and Sediments. IN: Submarine Canyons of Southern California. Allan Hancock Pacific Expeditions. Los Angeles: University of Southern California Press. 27: 80.

La Jolla Canyon was one of thirteen canyons studied; remarks are generalized to many or all canyons studied. Where possible, remarks relevant to La Jolla Canyon are abstracted below. Canyon soundings were made and topography examined. The depth of the La Jolla Canyon edge is not uniform across the continental shelf. Transverse profiles across the shelf portion of the canyon show a seaward deepening of the canyon edge. This deepening is somewhat greater than the general slope of the continental shelf and the profiles show some lateral slope of the shelf toward the canyon. Both facts mean that the topographic effect of the canyon extends somewhat beyond the narrow gorge of the canyon. Basin slopes in the region average about eight percent. La Jolla Canyon has a broadly curved course down the basin slope. Extensions of submarine canyons on the basin floor are recognized by low winding channels across the broad concave fan or apron built up of sediments carried down the canyon and deposited on the basin floor. The channel is bordered by natural levees which often cause the floor of the channel to be higher than the surface of the adjacent fan. Water samples (temperature, salinity, silicate, phosphate, oxygen) showed no marked difference in the character of the water at the canyon head from that near the seaward end of the canyon. The water is within the range of seasonal and areal variation of that in the adjacent basins though there is some slight inclination of the isopleth indicating possible downwelling in La Jolla Canyon. General remarks on sediment texture, calcium carbonate, and organic matter are made for all canyons studied and there is a table of La Jolla Canyon sediment data. Benthic fauna samples from La Jolla Canyon are abnormal consisting almost exclusively of Capitella, a polychaete worm which ordinarily lives in estuarine water. For a 0.6 square meter sample, the numbers of Capitella found at depth are: 595 (135m); 14,145 (274m); 948 (371m); 36 (517m); 1 (545m); 3 (637m); 5 (793m). These same samples are free of marine worms and of other marine animals except carnivores such as squid. Since Capitella lays its eggs in the tubes in which it lives, wide dispersion through sea water is unlikely. It is suggested that the samples represent sites at which fresh water escapes into the ocean from aquifers which have been intersected by cutting of the canyon.

Hartman, Olga (1963). Submarine Canyons of Southern California, Part II, Biology. IN: Submarine Canyons of Southern California. Allan Hancock Pacific Expeditions. Los Angeles: University of Southern California Press. 27: 424.

Studied thirteen canyons in Southern California including La Jolla Canyon. General conclusions that apply to La Jolla Canyon et al: (1) Each canyon is found to support a richly diversified fauna, high in specific entities; (2) The largest numbers of species in a canyon occur in shallowest, or continental shelf depths, and they are members of the continental shelf or continental slope fauna. There is a gradual decline in numbers of species (though not necessarily specimens) with depth, but there are deviations from this principle, perhaps partly due to factors other than depth; (3) Most species occur as single or few specimens in a sample; (4) Many species are represented by peak or high numbers in one or a few samples, from widely dispersed places. Such peak numbers may be correlated with optimum conditions for the species, with gregariousness, or with recent spat-falls of individual species, but not usually with food concentrations; (5) The replacement of species from one canyon to the next is such that from 30% to 60% are different. These difference may be partly correlated with latitude, with change in sediments, with distance from shore, or with other factors concerned with the biology of specific entities; (6) Replacement of species with a canyon with increasing depth is also abrupt, so that more than 50% of the species may differ from one depth class to the next. One of the most conspicuous differences between continental shelf and canyon faunas is the replacement of animal groups or genera or species from shelf depths to canyons. Animals that are well represented in the shelf can be sparse or nearly absent in most canyons. Brissopsid urchins, thalassemid echiuroids, and polychaetes comprise the largest part of the biomass values in canyons, from shallow to moderate depths. Where muds and silts prevail the first two are best developed, in median to low median depths. At shallowest and deepest stations the polychaetes occur in greatest masses, accompanied by molluscs in upper, and by ophiuroid echinoderms in lower levels. Benthic animals in shelf depths or heads of canyons near shore are mainly shelf species which have their more extended distribution in depths of less than 100 meters. In deeper parts of canyons, where sediments are chiefly mud, most of the animals are burrowing or tubicolous, and soft bodies. They exist in tubes or burrows, or move freely through the sediments. A few have thin shells or fragile calcareous skeletons. Their surface structures tend to be smooth and their shape orbicular or spherical or cylindrical. Phylogenetic groups best represented in canyons are polychaetes, echinoid and ophiuroid echinoderms, pelecypod molluscs, solenogaster molluscs, echiuroid worms, holothurian echinoderms, enteropneusts, and some small crustaceans (amphipods, isopods). It is assumed that many of the mud dwelling species are deposit feeders; others, such as nemerteans and coelentrates, are perhaps predators, and some of the pelecypods may be filter-feeders. La Jolla Canyon contained the same kind of screenings as the more southern Coronado Canyon. At 79 and 976 meters, there was fibrous debris; woody debris occurred in 371 and 637 meters, plant debris in 135, 274 and 517 meters. In its shallowest axes depths, the animals were chiefly those characteristic of lowered sainity. At its middepths the animals were those found at shelf depths, accompanied by much detritus; at its lowest depths, the animals were those of an abyssal fauna. Eleven samples came from 79 to 976 meters depth in La Jolla Canyon. Biomass ranged from negligible (coming from the largest or third deepest sample) up to 81.8 grams from a moderately large sample in 121 meters. Largest individuals in shallow, 79 to 121 meters, depths are Cerebratulus, a nemertean, Aphrodita, Asychis and other polychaetes. In

deeper, 545 and 637 meters depths, the largest are Brissopsis and Arhynchite. A diversified shelf fauna exists in 79 and 121 meters, as well as in shelf depths with algal debris farther from shore. Some species attain peak numbers; such are Aricidea lopezi with more than 310 individuals per sample in 79 meters, Ancistrosyllis tentaculata with 69 and Cossura candida with 86 in a sample. Axis depths, in 135 to 371 meters, have sediments of sand and pebbles; animals are almost entirely Capitella capitata subspecies, in tremendous numbers, with 14,145 individuals counted in a sample from 274 meters; some harbor an endoparasitic copepod, Monstrilla capitellicola. At middle depths, in 517 and 545 meters, the bottom is somewhat impoverished, with numbers of species and speciments reduced. In deeper parts a deepwater fauna exists, characterized by brissopsid urchins, some ophiuroids, Maldane cristata, Aricidea ramosa; and in its deepest parts an abyssal fauna is found; this includes pogonophores, Ophiacantha normani and some unusual polychaetes. In these respects this canyon shares some characteristics of the next adjacent Coronado Canyon. The total number of species reported for La Jolla Canyon samples is 126 polychaetes, 12 echnioderms, 23 molluscs, 18 crustaceans, and 11 others; molluscs and crustaceans are considered low because these groups are incompletely identified.

Hartman, Olga (1963). Submarine Canyons of Southern California, Part III, Systematics: Polychaetes. IN: Submarine Canyons of Southern California. Allan Hancock Pacific Expeditions. Los Angeles: University of Southern California Press. 27: 93.

List and some descriptions of the polychaetes found in the thirteen Southern California submarine canyons studied including La Jolla Canyon. Contains additional notes on other invertebrates found: Solenogasters; Pelecypods, Gastropods, Scaphopods, Gastropod Egg Case, Echiuroidea, Brachiopoda, Oligochaeta.

Shepard, Francis P. (1963). Submarine geology. New York: Harper and Row.

Discards subaerial (river eroded) formation hypothesis for submarine canyons presented in the first edition of this book which stated that the canyons were cut by rivers during a low stand of sea level caused by continental glaciers that were much larger and thicker than generally thought to have been the case. States that there are only two hypotheses left and makes a case for the latter: (1) turbidity currents cutting submerged canyons filled with marine deposits, and, (2) subaerial erosion combined with drowning and maintenance of the canyons by turbidity currents, submarine slides, sand flows, and abrasion by creep of the maps of sediment containing embedded rock and kelp in canyon heads. Canyons cannot be explained by one process alone; some canyons are now forming and have formed in the past including faulting (fault troughs). Description of La Jolla and Scripps Canyons on pages 312-317. Scripps Canyon has three tributaries at its head. The innermost head of South Branch of Scripps Canyon lies 230 meters from the low tide shoreline directly off Sumner Canyon on land. A rock gully continues to within

sixty meters of the shoreline through sand fill. The head is a sand chute which can be traced outward for a hundred meters to where rock appears on the walls and the valley enters a narrow gorge with a steeply sloping floor usually covered with sand, surf grass, and kelp. The rock on the canyon walls is stratified and wall slopes are vertical or overhanging. Tributaries enter the sides either as hanging valleys or as steep-floored ravines. Depths are subject to change due to sediment buildup and removal. Cliffed walls continue out to the point where Scripps Canyon joins La Jolla Canyon a mile from shore and at a depth of 150 fathoms. La Jolla Canyon has much less precipitous walls. At its head are alluvial formations which appear to be weathering back at an appreciable rate. A considerable number of branches come into La Jolla Canyon head. Large blocks are breaking away from the wall and the alluvium is being eroded. Farther down, the walls have rock outcrops, some of them Cretaceous and some Eocene. A number of dredge hauls on the walls beyond where La Jolla Canyon reaches three hundred fathoms failed to yield rock. The profiles show that the true canyon has apparently ended and is replaced by a channel with natural levees. Locally the channel has terraces on the side. Traced outward into San Diego Trough a fan with a channel becomes evident. The fan-valley decreases in depth until, merging with the fan, it disappears in the flat floor of the trough. Cores along the length of La Jolla Canyon beyond the confluence with Scripps Canyon show alternating layers of sand and silty clay. The same types continue all the way out to the end of the channel. Sand layers, however, are found also in the fan and on the levees on either side of the channel although the sand is somewhat less common.

Dill, Robert F. (1962). Sedimentary and erosional features of submarine canyon heads. IN: Proceedings of the First National Coastal and Shallow Water Research Conference. D. S. Gorsline: National Science Foundation and Office of Naval Research: 531 (abstract).

North, Wheeler J. (1962). "La Jolla's beautiful submarine canyon." Skin Diver Magazine 11(3): 18-21.

States that La Jolla Canyon starts in a muddy, shallow slope 25 feet deep, known as Sea Lion Gulch. Describes the scenery descending into the canyon from Sea Lion Gulch, as well as the southwest wall of the canyon. Describes running out of air at depth in the canyon. Has photos of Jim Stewart pointing to a fish, some canyon photos, and Conrad Limbaugh, and Charles Fleming with Indian mortars collected from the canyon.

Shepard, Francis P. (1962). "Submarine canyons of the San Diego-La Jolla area." Geological Society of America Special Paper 54: 68.

Shepard, Francis P. and Gerhard Einsele (1962). "Sedimentation in San Diego Trough and contributing submarine canyons." Sedimentology 1(2): 81-133.

The San Diego Trough basis has had sufficient sedimentation to fill the basin depressions so that there is a continuous slope southward to where the trough connects with the deeper San Clemente Basin. This deposition has apparently come to a very great extent from turbidity currents moving down canyons developing channeled fans at the canyon bases. All along the canyons and channels as well as across the fans and in San Diego Trough there are sequences of turbidite sands alternating with muddy sediments that represent the normal deep water sedimentation. Comparison of the coarse fraction from the sands and from the interbedded muds shows that the former are predominantly terrigenous in character whereas a large proportion of the latter are biogenous (mostly Foraminifera). Mica is quite low in the coarser sand layers but is abundant in the coarse fraction of the muds. Diatoms and radiolarians are largely confined to the mud layers where they may constitute a large precentage of the sand fraction. Study of the heavy and light minerals shows that the San Diego Trough sediments are derived largely from the nearby land masses rather than having a considerable admixture fom the north as would be the case if sediments were being brought down by turbidity currents coming into the trough from the north. The alterites are apparently lower in the San Diego Trough than in the near shore source area which suggests that a supply of sediments may be picked up from the canyon or channel walls along the way to the trough. Also the finding of the only coarse sands in the middle reaches of the channels suggests local sources as does the general make up of these coarse sands. Despite these locally derived coarse sands the prevalence of very fine sand and the mud layers between sand layers suggest that turbidity currents supplying sediments to San Diego Trough have low velocities or at any rate little erosive capacity. Scripps Canyon's rocky walls are largely shale, sandstone, and conglomerate of Eocene age. La Jolla Canyon head has alluvial cliffs, either Pleistocene or Holocene in age. About one thousand feet seaward from La Jolla Canyon's head, rock walls are found with the rock partly Cretaceous and partly Eocene. Beyond the juncture of Scripps and La Jolla Canyons below 300 fathoms, no rock has been found in wall dredgings and the canyon ceases to be a canyon and is referred to as the La Jolla Channel. This channel extends down a broad fan to a depth of 580 fathoms. The slopes are gentler and there are marginal ridges about ten fathoms high consisting of unconsolidated sediments (levees). Between 330-375 fathoms the channel has a terrace alternately on one side then the other. Farther out the channel narrows and is V-shaped. Around depths of 500 fathoms the channel is meandering and its walls are steeper on the outside of the curves as is the case in most river valleys. At the lower end of the fan at 600 fathoms, there are two very shallow channels that may or may not be distributaries of the continuous single channel that is found crossing most of the fan. In composition the constituents of most of the sand layers in the cores resemble the sands contributed to the Scripps Canyon head. The relatively high content of mica in all but the coarsest and cleanest sands is comparable with the equally high content in the sediments being transported along the coast towards the head of Scripps Canyon.

AMSOC Committee of the Division of Earth Sciences, National Research Council, National Academy of Sciences (1961). Experimental drilling in deep water at La Jolla and Guadalupe sites. Washington DC: National Academy of Sciences, National Research Council.

Five drilling cores to a maximum depth of 1,035 feet below seafloor were taken and examined from the La Jolla Fan Valley at a depth of 3,111 feet, where the channel is meandering and has steep banks on the outside of each curve. On both sides of the channel there are raised levee-like ridges that resemble delta levees, but have more relief, rising about sixty feet above surroundings. The drilling was made on the outher side of the western levee. Sediments in the cores were sands and silts, except for a section of dolomite cored from 751-761 feet below the sea bottom. In general, a greater abundance of sand layers of the "turbidity" type was obtained in the upper 300 feet of the cores, while green silts predominated from 300-1,000 feet. This apparent lithologic variation may be a function of the sampling devices used in the holes of different depths. Analyses are presented of grain size, chemistry and mineralogy, foraminifera, and roundness. The drilling reported here and at Guadalupe Island are the world's first oceanic drillings, using a drilling barge CUSS I.

Buffington, Edwin C. (1961). "Experimental turbidity currents on the sea floor." Bulletin of the American Association of Petroleum Geologists 45(8): 1392-1400.

Marine turbidity currents provide an explanation for many phenomena, the circumstantial evidence for their efficacy is convincing, but there is scant empirical evidence bearing on their mode of origin and none on the presence of high-density, high-velocity marine currents (velocities in excess of fifteen knots and densities greater than 1.20). Low-density, low-velocity turbidity currents have been seen, sample and measure mostly in lakes and reservoirs. Experiments intended to simulate natural conditions were conducted at the head of La Jolla Canyon at a depth of forty feet in an attempt to produce turbidity currents. Eight experiments were conducted by sliding a mass of pre-mixed sediment from an elevated, tilted container on La Jolla Canyon's sloping sea floor and observing the resulting flow directly. The initiation of a flow appears sensitive to the proportions of the sediment grain sizes and therefore cohesiveness of the sediment mass, the method of mixing, and total volume. Initiation on an open slope appears much less likely than on the walls of a confined feature such as a gully or canyon. Natural analogies do not tend to support the existence of high-density, high-velocity marine turbidity currents.

Dill, Robert F. (1961). Geological features of La Jolla Canyon as revealed by dive no. 83 of the bathyscaph TRIESTE. U.S. Navy Electronics Laboratory. Technical Memorandum TM-516. 1961.

Hartman, Olga (1961). "New Pogonophora from the eastern Pacific Ocean." Pacific Science 15(4): 542-546.

Siboglinum veleronis is described from La Jolla Canyon, in a depth of 976 meters. A bottom grab sample of 2.51 cubic feet in sediments of gray sand and green mud yielded 30+ species and 428+ specimens of living invertebrate animals of which Siboglinum veleronis comprised 100+. Other animals included polychaetes with 22 species and 200+ specimens; Maldane cristata was the most conspicuous and Paraonis gracilis oculata the most abundant. Others were a small white anemone, an ostracod, an amphipod, a cumacean with 2 specimens, a gnathid isopod with 2 specimens, 2 kinds of ophiuroids with 24 specimens and some siliceous sponge spicules. The animals weighed (moist) 6.4 grams. S. veleronis is compared with 10 other known species of the genus and their known geographic distribution indicated. Six species are limited to the northwestern end of the Pacific Ocean; 3 others occur in the northwestern end of the Atlantic Ocean, 1 is from the Malay trench in great depths. S. veleronis is the first described from the eastern Pacific Ocean, coming from latitudes south of 33 [degree] North.

Inman, Douglas L. and Earl A. Murray (1961). Mechanics of sedimentation. Scripps Institution of Oceanography. ONR Progress Report January 1 - June 30, pp. 11-13. 1961.

Shepard, Francis P. (1961). Deep-sea sands. IN: International Geological Congress, Report of the Twenty-First Session Norden, Denmark, Finland, Iceland, Norway, Sweden, 1960. Part XXIII, Proceedings of the International Association of Sedimentology. K. Hansen. Copenhagen: Det Berlingske Bogtrykkeri: 26-42.

Deep sea sands were studied by size analysis and microscopic determination of constituents and compared with sands deposited in shallow waters. Describing deep sea sands as graded is inaccurate. Along the length of some of these layers there are repeated alternations between coarse and fine sediments. Others show little change in grain size along the length. Most of the sands are coarser at the bottom than at the top. In general deep sea sands contain a sizeable quantity of coarse silt and are similar to shallow water sands found on the nearby continental shelves. There appears to have been considerable loss of such organisms as Foraminifera and echinoids during the transportation of sand from shallow water. On the other hand some Foraminifera appear to have been added to the sediments along the route. Deep sea sands are not a concentrate due to winnowing of the sand-sized particles of deep sea sediments because the latter consist primarily of plantonic Foraminifera which are scarce in most deep sea sands. Turbidity current origin of deep sea sands appears well established. Sands from La Jolla Canyon and Scripps Canyon were included in this study; samples went from the canyon heads down through the fan. A considerable per cent of the approx one hundred

cores taken from the canyon and fan contain sand layers. they are mostly thin layers between clayey sediments although a few cores have relatively thick sand. There is a progressive change in the sand character (size and constituents) going outward from shore and downcanyon. One decided increase in sand size was found near the middle of the canyon samples (about 450 fathoms). For the canyons, mica content is relatively high but quite variable with some general increase out along the fan. The most abundant mica occurs in about fifteen fathoms at the canyon head. The coarse sediment found in the channel (about 450 fathoms) is very angular and largely quartz, much of it with inclusions of other minerals and with a small amount of pyrite and chalcopyrite this sand differs from La Jolla beach sands although it compares in size with the much rounder sand in some of the coves around Point La Jolla. The canyon cores are partially graded and have no pronounced increase in coarseness at the bottom of the layer. Mica shows some decrease with depth.

Chamberlain, Theodore K. (1960). Mechanics of Mass Sediment Transport In Scripps Submarine Canyon, California. Ph.D dissertation, University Of California, Los Angeles.

Emery, K.O. (1960). The sea off southern California, a modern habitat of petroleum. New York: John Wiley.

Throughout the book whenever applicable, geological aspects of submarine canyons in Southern California including Scripps and La Jolla canyons is discussed.

Inman, Douglas L. and Theodore K. Chamberlain (1960). Littoral sand budget along the southern California coast. 21st International Geological Congress, Copenhagen. pp. 245-246.

Uchio, Takayasu (1960). Ecology of living benthonic Foraminifera from the San Diego, California area. Ithaca, NY: Cushman Foundation for Foraminiferal Research.

One hundred and fifty-seven samples from the sea floor off San Diego, California, were studied for both living and total (living plus dead) populations of Foraminifera. Seven benthonic Foraminifera depth assemblages are recognized on the basis of the living distribution and abundances. The boundaries are at depths of approximately 13, 45, 100, 250, 350, and 450 fathoms. Based on the Scripps Institution's study of hydrography it appears that the 13-fathom boundary may be interpreted as approximating the base of the turbulent zone, the 45-fathom boundary the bottom of the seasonal thermocline, the 100-fathom boundary the bottom of the California current, the 250-fathom boundary the top of the permanent thermocline, the 350-fathom boundary the oxygen minimum layer,

the 450-fathom boundary the bottom of the permanent thermocline. The shallowest assemblage is divided into 2 facies, and difference of sediment types may be one of the principal causes of such differentiation. Comparison of depth ranges of living and empty tests of 95 species shows that some of the tests of almost all species are transported toward deeper water after death. Total population counts are valid in defining the general composition and distribution where little or no displacement of sediment is expected, but generally these counts are not indicative of distribution of living specimens. Maximum abundance of living benthonic Foraminifera occurs between 55 and 150 fathoms and approximately coincides with the greatest number of species and genera. Temperature, food, and sediment type are considered important factors for depth distribution and size of population of living benthonic Foraminifera. Ratios of living to total populations from sediment samples appear to be indicative of the rate of sedimentation. The ratios support the suggestion of Dietz that sediments from the land are deposited either nearshore or on the lower part of the continental slope and in basins, bypassing the outer shelf and upper continental slope. Rates of sedimentation calculated from an assumed rate of reproduction of Foraminifera are 97 years per cm. of sediment in the San Diego trough and 0.36 years per cm. in the nearshore area. Three methods of calculating the amount of sea-level change by using benthonic Foraminifera are discussed. Five to 10 fathoms of deepening is suggested at some time later than the Pleistocene. The presence of shallow-water Foraminifera and Pleistocene Foraminifera in sand layers of a clayey silt core, and in sandy silt on the surface of the floor of the San Diego trough, where clayey silts usually are found, proves displacement of sediments from shallow to deep water. Siltstones were cored at 3 stations in and near Loma sea valley and Coronado canyon, and are Miocene in age based on assemblages of Foraminifera, diatoms, and Radiolaria. One hundred and sixty species of benthonic Foraminifera are figured, of which 70 species are discussed as to their ranges of variation of forms and or synonymies.

Emery, K.O. (1958). "Shallow submerged marine terraces of southern California." Geological Society of America Bulletin 69: 39-60.

Ghelardi, Raymond J. and Wheeler J. North (1958). "A possible ecological effect of upwelling in a submarine canyon." Nature 181: 207-208.

During July-November 1956, an exploratory ecological survey along the south-west edge of the La Jolla Canyon was conducted over a sandy bottom using scuba diving. There are sharp changes in the dominant species of animals as one swims toward the northwest along the canyon axis between the 27- to 37-meter contours. In the shoreward regions abundant populations of the sea-pen, Stylatula elongata, and the sea-star, Astropecten californicus, exist. Abruptly the community changes and is almost entirely Astropecten for about 50 meters. Continuing farther, brittle stars, Ophiura lutkeni, are found almost exclusively. On the, broad, sandy continental shelf to the north Ophiura are not found until a depth of 47—50 meters is reached ; Astropecten here occurs at 40-23

meters and Stylutula at 23-10 meters. Boundaries between communities on the shelf appear to run parallel to the depth contours; at the canyon they run across the contours. 100-150 meter traverses were swum near the 30-meter contour along the edge of the canyon through these regions. Centrally within these regions counts of animals were made in areas chosen at random by quadrats cast down blindly. Marked differences were found. The areas on the canyon rim are not characterized by any large differences in substrate, depth and temperature. We have, however, while on the bottom in one area, observed water currents coming from the direction of the canyon travelling up slopes as steep as 26°. Current velocities are variable both in magnitude and direction; but this is characteristic of near-shore currents in southern California. Velocity measurements, determined by timing the progress of a cloud of permanganate solution for 1 meter, yielded vertical components as great as 45 centimeters/minute upwards. Studies have as yet failed to give evidence of upwelling; this difference may be an important factor influencing the distributions discussed above. The commercially harvested kelp beds of Macrocystis pyrifera just south may also be affected by the upwelling. Tides, internal waves, and northerly currents could contribute to the upwelling; the biological data suggest that northerly currents may play an important part. Ophiuran populations occurring at fifty meters depth on the shelf and at thirty meters in the canyon allow the possibility of a water mass common to both places. Currents from the north at the fifty meter depth would run into the south wall of the canyon and may upwell and flow across this region. Some areas below 27 meters are protected from northerly currents by the shoal opposite wall of the canyon.

Limbaugh, Conrad and Francis P. Shepard (1957). Submarine canyons. IN: Marine Ecology. Geological Society of America Memoir. J. Hedgepeth: Geological Society of America. 67(1): 633-639.

Studied the La Jolla Canyon fauna based on diving and on dredging and photography.. Gives a long list of species including fish and invertebrates, chiefly those to be expected in continental shelf depths. Three kinds of plants noted: Zostera above the rim on the south side; elkhorn kelp as isolated plants, and Macrocystis attached to large cobbles. The most conspicuous animals inhabiting the sandy bottom were large burrowing clams and a ceriantharid anemone. Rocky outcrops supported attached purple gorgonians and vermetid gastropods; other surface dwelling forms included starfish, sea cucumbers, large snails and a few purple sea urchins. On two occasions the egg capsules of the squid Loligo opalescens were abundant. The invertebrate animals named are chiefly continental shelf species attached to hard substrata, or existing in sandy or shaley or rocky bottoms. The study did not extend in the deeper parts of either La Jolla or Scripps canyons.

McAllister, R.F. (1957). "Photography of submerged vertical structures." American Geophysical Union Transactions 38(3): 314-319.

Made pictures of the outer cliffs of La Jolla Canyon by pulling a submerged camera toward the wall with a projecting rod so as to obtain a flash photo at proper focus when the rod made contact.

Inman, Douglas L. and Theodore K. Chamberlain (1955). Particle size distribution in nearshore sediments. IN: Finding ancient shorelines: a symposium sponsored by the Society of Economic Paleontologists and Mineralogists. Society of Economic Paleontologists and Mineralogists Special Publication Number 3. J. L. Hough and H. W. Menard. Tulsa, Oklahoma: Society of Economic Paleontologists and Mineralogists: 106-129.

Presents pattern of seasonal and environmental variation in sediment distribution along the beach and sandy shelf from La Jolla Canyon to Scripps Canyon and including sample sites within each canyon. The sediments on Scripps Beach and inter-canyon shelf are grouped into three types: Type I consists of beach foreshore sands, which are the best sorted sediments in the La Jolla area. Sands from the surf zone are designated as Type IIa, and are characteristically coarser and more poorly sorted than adjacent sediments inshore or offshore. These grade into Type II which are found on the relatively flat portions of the shelf from the surf zone out to depths of approx 100 feet, and are therefore the most abundant sediment on the inter-canyon shelf. Type II sediments are predominantly well-sorted, very fine sands, with less than about three percent silt. Seaward of the Type II sediments in areas where there is sloping bottom, the silt content usually increases, the sediment characteristically has a positive skewness, and is more poorly sorted. These sediments are classed as Type IIIa, and while usually occurring in deeper water, they are also found in shallow water near the canyon heads. Because they occur only where the bottom slopes are greater than about 1:15, sloping bottom may be an important environmental factor and they are referred to as slope or transitional sediments. The reduction in wave action over the sloping bottom apparently allows fine sediments to accumulate along with the sand sized material from further up slope. Also, the presence of a slope helps to reduce the sorting effect of the wave motion. This is a transition zone where fine material settles out because of reduced wave intensity, and sand size material is introduced by gravity movement down slope. Sediments from the beach and shelf north of SIO were similar to those on the inter-canyon shelf except that the northern beach sands were slightly coarser and the shelf sediment somewhat finer than their counterpart from the inter-canyon shelf. The difference in shelf sediments is due to Scripps Canyon which prevents the transportation of sediments in deep water from one shelf to the next except as suspended load. Therefore the main source of inter-canyon sediment is sand size material transported across the shallow shelf at the head of the canyon. The sediments on the rocky shelf around Point La Jolla differ markedly from those of the inter-canyon shelf. The transition between the Point La Jolla shelf sediments and the fine sands to the north occurs near the head of La Jolla Canyon and results in a confused sediment distribution. These sediments are classed as Type V and are bi-modal, sorted, and have a low shell content.

Wimberley, C.S. (1955). "Marine sediments north of Scripps Submarine Canyon, La Jolla, California." Journal of Sedimentary Petrology 25(1): 24-37.

According to Shepard & Dill, 1966, recent shelf sediments surrounding Scripps Canyon are entirely different in composition and structure from those found within the canyon head. The shelf sediments are relatively clearn, homogeneous, fine-grained quartz sand (Inman, 1953; Wimberly, 1955) whereas the canyon fill is composed of a heterogeneous mixture of interbedded layers of micaceous silty sands and matted organic debris of marine plant origin (Chamberlain, 1960; Dill, 1964).

Arthur, Robert S. (1954). "Oscillations in sea temperature at Scripps and Oceanside Piers." Deep-Sea Research 2(2): 107-121.

Observations of sea temperature have been made in the vicinity of Scripps Pier at stations inshore and between La Jolla and Scripps Canyons and at Oceanside Pier. Temperature-depth curves and temperature profiles show a shallow thermocline during the warm months. The depth of the thermocline varies with time, and, as a result, thermograms from fixed depths at the pier ends show oscillations. Changes of five degree Celsius over a time interval of hours are frequent as the intersection of the thermocline with the sloping bottom moves inshore and offshore. Thermograms from the two piers show no obvious coherence in the oscillations, but over a distance of four kilometers along the Scripps shore there is evidence of coherence. Oscillations in the thermograms suggest the possibility of tidal periodicities but without the persistent regularity demonstrated for surface tides. An internal wave mechanism is consistent with the data. Internal waves have been confirmed in deeper water in the general area, and the oscillations can, therefore, represent the effect near the shore of internal waves of various periods, including tidal. Applications to marine biology, underwater sound, and sedimentation are mentioned. It is suggested that coastal piers offer bases for economical operation of gauges which will help to determine the existence and nature of internal-tide waves.

Dill, Robert F. (1954). "Deep dive to 225 feet in the Scripps Submarine Canyon." Skin Diver 3(6): 3,12-13.

A dive of 225 feet into Scripps Canyon was made on 31 July 1953 by Hugh Bradner, Conrad Limbaugh, and Robert Dill. Raymond McAllister was a safety diver. The dive's purpose was scientific observation, and Scripps Institution of Oceanography Aqua-Lung instructor certification for Dill. Divers wore Bradner-designed neoprene wetsuits. The dive was made at the junction of Sumner and South branches of Scripps Canyon. Divers observed the debris mat on the canyon bottom and then headed back up,

observing the canyon walls as they ascended. Dive time before the first decompression stop was fifteen minutes

McGowan, John A. (1954). "Observations on the sexual behavior and spawning of the squid, Loligo opalescens, at La Jolla, California." California Fish and Game 40(1): 47-54.

An unusually large spawning population of the Pacific Coast squid, Loligo opalescens, appeared during February and March 1953. For a week before February 16, 1953, large squid schools had been in the vicinity of La Jolla Canyon about 1400 feet offshore. A dive was made inshore of Scripps Canyon at 50 feet on March 8, 1953; water temperature was 12.6 degrees C. Mass squid mortality was taking place with the bottom littered with dead and dying squid at 1-2 individuals per square foot for a 75-100 yard survey. A large mass of egg capsules was attached to the sandy bottom along the 50 foot contour about 10-15 feet in diameter with actively swimming, spawning, and egg-laying squid in the immediate vicinity. On March 9, 1953, a dive was made at the head of La Jolla Canyon; water temperature was 12.4 degrees C. Large schools of squid were seen in the waters immediately above the canyon. As many as a dozen large egg masses were seen; one was estimated to be at least 40 feet in diameter. These masses were concentrated along the edges of the canyon, some of them being on the more gentle slopes and shelves of the canyon wall itself. One egg mass extended from 70 feet down to 114 feet and appeared to continue further. Dead squid were observed at the 40 foot contour. Squid were actively swimming, spawning, and egg-laying. Subsequent dives concentrated on an intensely squid spawning branch of La Jolla Canyon known as Sea Lion Gulch. Dives and bottom and surface plankton hauls were made every third day during the second and third weeks in March. After this, only weekly dives and plankton hauls were made for the next five weeks. Examination of the guts of the females collected showed them to be completely empty; male guts contained only a few shreds of mantle epidermis which had apparently been torn from the female. A 40 cm Hansen type plankton net was used to make ten minute hauls over the vicinity of Sea Lion Gulch. Hauls were made at the surface and close to the bottom for six weeks after the main spawning was observed. Only four larval squid were caught in these hauls, although diving observations made at the time of the hauls indicated that the number of egg capsules was progressively decreasing. The results of the plankton hauls indicate that larval squid did not stay in the vicinity of the spawning grounds and were swept away by currents. Egg capsules were observed infected with a large, bright red polychaete worm Capitella ovincola which appeared to be merely boring through the gelatinous matrix of the egg capsule and not feeding on the developing squid embryos. The sequence of events in squid spawning is: (1) A population ready to spawn moves from offshore into a relatively shallow area near shore. Males transfer sperm to the buccal seminal receptacles of the females. This method of fertilization was not observed by the divers so the authors deduce that it is used previous to squid arrival in La Jolla. (2) Squid congregate near the sandy bottoms of semiprotected bays. (3) A few minutes before the females lay their eggs, the males transfer a second group of spermatophores to a place under the left side of the mantles of the females. Divers observed this method of

fertilization. (4) Females attach their egg capsules either to the sandy bottom or to the base of some previously laid egg capsule. (5) Both males and females die after spawning. (6) Eggs require 30-35 days to hatch at a temperature of 13.6 degrees C.

Wimberley, C. Stanley (1954). Marine sediments north of Scripps submarine canyon, La Jolla, California. Masters thesis, University of Texas, Austin.

Examination of 72 beach and bottom samples north of Scripps Canyon reveals that the area is occupied by five geographically distinct sediment types, based upon grain size. One class, an isolated area now under forty fathoms of water, contains coarse particles suggestive of a former beach on the rim of the La Jolla Canyon system. The other four classes display a strikingly linear correlation of grain size with depth of water. The equation for determining mud content is mud percentage=1.74(depth in fathoms)-1.93 . A sharp change in mud percent is found at thirty fathoms, which may correlate with the seaward limit of eddy water circulations near shore. Determination of mineralogic and biologic content shows that the sands consist chiefly of subangular quartz with abundant feldspar. Good evidence of the widely different hydraulic properties of mica and dark minerals is shown by the correlation of these two minerals with depth. Organic remains are uniformly distributed throughout the area. The apparent absence of a submarine canyon offshore from Soledad Valley (the valley just north of Torrey Pines State Park) suggests that the forces which clear and preserve Scripps and La Jolla canyons are lacking further north.

Inman, Douglas L. (1953). Areal and seasonal variations in beach and nearshore sediments at La Jolla, California. US Dept of the Army, Corps of Engineers, Office of the Chief of Engineers, Beach Erosion Board. Technical Memorandum No. 39.

According to Shepard & Dill, 1966, recent shelf sediments surrounding Scripps Canyon are entirely different in composition and structure from those found within the canyon head. The shelf sediments are relatively clean, homogeneous, fine-grained quartz sand (Inman, 1953; Wimberly, 1955) whereas the canyon fill is composed of a heterogeneous mixture of interbedded layers of micaceous silty sands and matted organic debris of marine plant origin (Chamberlain, 1960; Dill, 1964).

Buffington, Edwin C. (1952). "Submarine "natural levees"." Journal of Geology 60(5): 473-479.

Natural levees fringe subaerial streams of low gradient which periodically experience overbank floods onto wide floodplains. Submarine features resembling levees have been found in several places on the West Coast including the La Jolla Fan Valley. The La Jolla Fan Valley site in this paper is at 3,390 feet depth near the base of Thirtymile

Bank. It is V-shaped in cross section. One levee with a sharp crest is higher by at least thirty feet than the other levee which has a flat crest. The La Jolla Fan Valley channel has a sinuous character. It originates where La Jolla Canyon debouches into San Diego Trough and can be traced across the floor of the Trough to the vicinity of Thirtymile Bank. Most of the profiles crossing the channel show natural levees. It is believed that levees are the products of deposition from turbidity curretns or submarine mudflows. If one levee is larger than the other, it may be caused by a flow overriding the outer edge of a curve in the channel.

Crowell, John C. (1952). "Submarine canyons bordering central and southern California." Journal of Geology 60(1): 58-83.

The characteristics of California submarine canyons between Monterey and San Diego differ from land canyons, suggesting that their origin is not subaerial (river eroded) but is submarine: longitudinal profiles are steeper than those of most land canyons; profiles are more irregular; canyons head near or at sea-level but extend to different depths, some greater than ten thousand feet; etc Geologic data show that the heads of several canyons including Redondo Canyon cut Upper Pleistocene and Recent sediments and that no land stream has issued into the Redondo Canyon head during that period. These arguments and other suggest that California submarine canyons were cut by submarine processes which are still operating today in some canyons. Wave-approach and refraction studies along the California coast, with observations, show that considerable sediment brought to the sea by land rivers is moved along the coast by longshore processes. California submarine canyons occur where (1) a supply of sediment is brought to canyon heads by these shore processes, (2) a relatively steep offshore slope heads close to shore, and (3) the transporting power of the longshore current slackens, usually because of coastal configuration. The canyons are probably eroded by the seaward movement downslope under gravity of sediment by some kind of sediment flow, turbidity, density, or suspension current. Discusses La Jolla and Scripps Canyons in general terms as part of a larger discussion with no new experimental data or observations.

Fisher, Robert L. and Richard Mills (1952). "Sediment trap studies of sand movement in La Jolla Bay." Bulletin of the Geological Society of America 63: 1328 (abstract).

Used a multi-sock sediment trap designed to separate the onshore, offshore, and longshore components of sediment transport. Sand caught by the trap in the shallow head of Scripps Canyon have a decidedly higher mica content than those from like depths on the open shelf under similar wave conditions. Mud was present in small quantities in samples taken in the canyon during a heavy rainstorm, but there was no evidence of increased sand transport under these conditions.

Inman, Douglas L. (1952). Areal and Seasonal Variations in Beach and Nearshore Sediments at La Jolla, California. PhD dissertation, University of California, Los Angeles.

Incorporates data on the seasonal distributions of physical properties of sediments at La Jolla and Scripps Canyon heads but is primarily focused on the whole beach including north, south, and intercanyon. Seasonal variations (wave energy, direction of wave approach) are of lesser magnitude than the average change in properties from one environment to another, such as from the beach to the surf zone or from shelf to slope. The effectiveness of Scripps Canyon in limiting longshore transport to the narrow zone of shallow water at the head of the canyon is indicated by the relatively coarse sediments on the intercanyon shelf, as compared with sediments from comparable depths on the shelf north of the canyon, even though the beach sands are finer along Scripps Beach than on the beaches to the north.

Kuenen, P.H. (1952). "Classification and origin of submarine canyons." Koninkl. Nederl. Akademic Van Wetenschappen Amsterdam, Series B: Physical Sciences 55(5): 464-473.

No one model explains submarine canyon origin. Some canyons are drowned land valleys and others are the result of turbidity currents during the Ice Age. Some may be due mainly to submarine land sliding or to tectonic activity. Submerged land valleys have been modified by submarine processes (sedimentation, marine planation, turbidity currents). Stream erosion has acted above glacial sea level in some canyons and turbidity currents have eroded some canyon heads in post-glacial times. An important form of composite origin is the local outcrop of ancient smothered topography in the walls of canyons cut by turbidity currents. Each mechanism produces its own canyons and there is no general model for submarine canyons due to the numerous transitional types in which two or more of the processes have been active. Kuenen modifies his past view and also Shepard's. Instead of postulating drowned canyons kept open by submarine processes, an ancient land of high relief was drowned and almost completely smothered by sediment. During the Ice Age turbidity currents became active and cut canyons in the poorly consolidated, newly deposited cover. Old canyons like Scripps Canyon were exhumed. Canyons are newly developed features and not old persistent furrows in the sea floor. Little indication of a deeply dissected land surface has remained on the submarine ridges of the offshore border land. The close spacing in some areas adjoining long stretches of coast line with no canyons, against the wide spacing elsewhere is very different to the persistently close spacing on a deeply dissected land slope. This indicates that sedimentation has succeeded in smothering the drowned topography effectively. Canyons tend to occur in locations favorable for the generation of turbidity currents during glacial low sea levels (heading at the break in the slope of the continental terrace, off river mouths, to windward of headlands). It might be argued from Shepard's point of view that only the drowned valleys which were favorably situated were kept open but this would indicate that turbidity flow and not sliding has been the dominant process involved.

Shepard's hypothesis doesn't account for the failure of the canyons to pass inside the coast line, although a dozen head at the beach. There is no reason why ancient valleys should have been restricted in length by the much younger present shore line. Had they passed further inland the slumping process invoked by Shepard should have been able to keep the portion indenting the coast line open. The canyon direction is controlled by the dip of the present continental slope (parallel on straight slopes, convergence in hollows) with only a few marked exceptions. Bends in submarine canyons are widely rounded because turbidity currents cannot follow sharp turnings nearly as easily as land streams can. Broad flat-bottomed valleys should be expected among those drowned long ago. Tectonic disturbance of valleys during and after subsidence would have caused reversal of the outward grading of some valleys, this resulting in sediment-filled basins with flat floors by the action of Shepard's slides. But flat floors of any extent are extremely rare and available data do appear to favor the turbidity current mechanism. There is strong evidence that the Californian submarine canyons including La Jolla and Scripps Canyons were eroded in a rather smooth submarine topography by a submarine process which started in the recent past. It has continued to act until the present in canyons approaching th beach if not by erosion in hard rock then at least by sweeping and soft rock erosion. But this current activity has ceased in those heading far out to sea. Shepard claims that several canyons show ancient deltas at their mouth, modified by slumping and non-depositional channels formed by turbidity currents. The so-called deltas are more like fans deposited by slumps and especially by turbidity currents where the slope decreases and the confining influence of the canyon walls ceases. There is no evidence in favor of assuming old deltas buried beneath present depositional fans. Levees along the lower reaches of some canyons provide evidence for turbidity flows at a vast scale because the currents must have topped the levees in order to build them up.

Shepard, Francis P. (1952). "Composite origin of submarine canyons." Journal of Geology 60(1): 84-96.

Submarine canyon origin is explained by: subaerial excavation of portions of the canyons at various times during the past when the margins were elevated above the ocean level; building of deltas on the outer slopes during this excavation; submergence of the canyons, with some accompanying fill but with preservation of the canyons through slides and turbidity currents acting along the old canyon axes; reshaping of the old deltas, with some enlargement of shallow trenches characteristic of steep delta fronts; marine deposition on the old land surfaces into which the canyons were cut but concurrent maintenance of the canyons by slides, so that the canyon walls grew higher as the submergence continued; and, the reshaping of the canyon heads by the Pleistocene sea-level changes of a few hundred feet. This composite sequence is supported by detailed soundings in the San Diego area and other evidence as well as a review of the supporting literature. In presenting evidence for this composite theory with respect to longshore transport and sediment deposition in canyons, there is a figure of the longshore drift in the La Jolla Canyon are accompanying a northwest wind, showing a current along Point La

Jolla directly north of the point and well south of the canon. Other than this, there is no new experimental data or observations on La Jolla Canyon or Scripps Canyon.

Williams, E. Allan and John D. Isaacs (1952). "The refraction of groups and of the waves which they generate in shallow water." Transactions of the American Geophysical Union 33(4): 523-530.

A wave process is described which may be of importance in beach and near-shore development and which may account for surging in the surf zone as well as other phenomena. It is shown how a wave group front may be refracted according to one law as it approaches a coast and then, after reflection, proceed seaward under quite a different law. This permits the outgoing wave to move in a direction that it could not ordinarily attain, and causes "trapping" under many conditions. Stoneley's theory of refraction of energy fronts is further developed to permit quantitative investigation of group refraction on various types of shores. On the basis of the assumed hypothesis, the outgoing surf beat may be totally reflected from deep water, then reflected from the beach, a process which can occur repeatedly and result in newly arriving groups with variable phase relationships. Theory and techniques are developed for the investigation of the surf-beat path. Refraction is graphed offshore La Jolla for waves coming in across La Jolla and Scripps Canyons. The refraction of the reflected groups is shown to display regions of high convergence, divergence, and reinforcement.

Menard, Henry W. and John C. Ludwick (1951). Applications of hydraulics to the study of marine turbidity currents. IN: Turbidity currents and the transportation of coarse sediments to deep water: a symposium. Society of Economic Paleontologists and Mineralogists, Special Publication 2. J. L. Hough. Tulsa, Oklahoma: Society of Economic Paleontologists and Mineralogists: 2-13.

Hydraulic observations and theories applicable to marine turbidy currents are summarized and discussed: (1) the probable density of marine turbidity currents, (2) the development of boundary waves, (3) the effect of a vertical density gradient in turbidity currents, and (4) the development of interflows in a stratified ocean. The behavior of marine turbidity currents in eroding, transporting, and depositing sediment is inferred. La Jolla Canyon is used in discussion as follows: A delta-like fan lies at the mouth of La Jolla Canyon where it debouches on the floor of the San Diego Trough. A sinuous channel, bounded in some places by parallel ridges which resemble levees, crosses the fan and extends onto the flatter floor of the trough. A study suggests that sediment moves to the floor of the San Diego Trough by some process of mass movement. If this movement occurs in the form of turbidity currents, the fluviatile type of topography suggests that turbidity currents on the flat sea floor behave like rivers in their lower reaches. They build deltas where the slope of the channel decreases abruptly. They flow within leveed

channels across the delta. Sediment deposited by current moving in these channels probably is also channelized.

Phleger, Fred B. (1951). Displaced Foraminifera faunas. IN: Turbidity currents and the transportation of coarse sediments to deep water: a symposium. Society of Economic Paleontologists and Mineralogists Special Publication 2. J. L. Hough. Tulsa, Oklahoma: Society of Economic Paleontologists and Mineralogists: 53-65.

Benthic Foraminifera were examined in sands from the San Diego Trough. A mixed fauna of shallow-water and deep-water species of Foraminifera are found at certain levels in sediment cores obtained from specific areas of the San Diego Trough. This suggests episodic movement of sand downslope from La Jolla Canyon to these locations in the San Diego Trough, through turbidity currents or other mechanisms. Some material seems to have been deposited as a mass movement of sediment from shallower water, without mixing with other sediment, and have only shallow-water species.

Shepard, Francis P. (1951). "Mass movements in submarine canyon heads." Transactions of the American Geophysical Union 32(3): 405-418.

The repetition of sounding profiles along precise ranges at the heads of Scripps Canyon has given a sequence of depth changes during the past three years. Changes up to a maximum of 21 ft have been observed. Fill and deepening have alternated, but without any seasonal relationship such as occurs on the local beaches as a response to storm waves. The shallow valley heads are shown to shift in position, and at least one new valley with a maximum depth of sixteen feet was formed during the period on an undissected slope. These changes have taken place on the sand-covered slopes inside the rock gorges and appear to be explained by sedimentation and landsliding. The latter may be a combination of creep and sudden shifting of sediment. Sufficient material is being moved by these slides to fill the outer gorges in a matter of a few centuries, but the material is certainly being carried out of the gorges, probably going to form the sand layers in the deep outer trough at the mouth of the canyon. The canyon heads are thought to trap a large proportion of the sand that is carried along the shore by currents. This prevents the formation of sand beaches directly down current from the canyons.

Shepard, Francis P. (1951). Transportation of sand into deep water. IN: Turbidity currents and the transportation of coarse sediments to deep water: a symposium. Society of Economic Paleontologists and Mineralogists Special Publication 2. J. L. Hough. Tulsa, Oklahoma: Society of Economic Paleontologists and Mineralogists: 53-65.

Well-sorted sand in deep water in excess of 250 fathoms (1500 feet) has been discovered in many places worldwide including La Jolla Canyon. The nature of sand

layers in between typical deep water deposits suggests rapid emplacement by some type of flow, presumably turbidity currents. The sand appears to be carried seaward along the axes of canyons, the currents being generated by landslides at the heads of the canyons. No evidence has been found to indicate that these flows are capable or cutting the rock gorges of the canyons. The evidence in the San Diego Trough and La Jolla Canyon suggests that sand is carried to its present deep-water environment by a combination of slumping and turbidity currents. Slumps such as are known to occur in shallow canyon heads may be converted into turbidity currents carrying some of the coarse sediments out along the canyon axes depositing it on the floors of troughs and basins beyond. Accumulation of decaying kelp and eel grass in canyon heads may have an important effect in permitting the sand slides to occur since the decomposition gas will decrease sand cohesion. Unsuccessful attempts were made using explosives to develop long-lasting sand slides or turbidity currents in Scripps Canyon that would reach one to two thousand feet down canyon. A series of profiles are repeated in Scripps and La Jolla Canyons several times a year. To date there have been few changes in La Jolla Canyon, but the tributaries at the head of Scripps Canyon are constantly being filled and reopened. The fill consists largely of sand, but a great abundance of eel grass and kelp is deposited in the canyon, accumulating with the sand. The gas released by this decaying vegetation must decrease the cohesion of the sand. Water and gas pockets associated with kelp and eel grass mst be helpful in setting off slides in the sand accumulating on steep inclines. It has been estimated that the slides from Scripps Canyon head displace more than one million cubic feet of sand every year. Figure 4 shows the cycle of cut and fill in the nearshore heads of two Scripps Canyon tributaries, at contour intervals of five feet, between January 1948 and March 1949 and between October 1949 and February 1950. Figure 5 shows differences in depth in another Scripps Canyon area between Sept 1948 and Feb 1950.

Shepard, Francis P. (1951). "Submarine canyons: a joint product of rivers and submarine processes." Science 114(2949): 7-9.

Notes abandonment of hypothesis that submarine canyons are the result of the lowering of sea level due to ice cap formation. Presents composite hypothesis of canyon formation without appealing to either enormous movements of land or of sea level or to the excavation by powerful submarine current for which there is no evidence. Cites La Jolla Canyon in the evidence.

Shepard, Francis P. and Douglas L. Inman (1951). Sand movement on the shallow inter-canyon shelf at La Jolla, California. US Dept of the Army, Corps of Engineers, Office of the Chief of Engineers, Beach Erosion Board. Technical Memorandum No. 26. November 1951.

Scripps Canyon and La Jolla Canyon, the two main branches of La Jolla Canyon, extend in to within about 700 feet of low tide shore line. Between these canyons there is a triangular shelf area with its apex a mile from shore and a base consisting of the relatively straight shore which runs for a mile and a half between the canyons. This province, consisting of shelf and beach, might represent somewhat of an isolated area receiving little sediment from the outside due to the barriers represented by the canyons on each side and therefore that it might be of special interest in determining the seasonal shifts of sand which are known to accompany the seasonal changes in wave height, period and direction of-approach. The nature of changes in sand level of this area has been indicated by eight repeated surveys accompanied by five sand sampling operations. It is believed that these surveys establish significant cut and fill out to depths of at least one hundred feet. During large waves sediment is lost to the area by transportation into the submarine canyons. Replenishment of the sediment is apparently due to transport around the head of the northern of the two canyons. The amount of sand introduced in this way is estimated to be of the order of 100 times as much as introduced from erosion of the land adjacent to the intercanyon area. On the other hand, little sand is carried around the southern canyon. Along and near the shore, sand is moved seaward during large waves and landward during small waves. With diagonal approaching waves much sand is carried along the coast. On the outer shelf the movement takes place more parallel to the shore than normal to it.

Kuenen, P.H. (1950). Geomorphology of the Sea Floor, Chapter Seven. IN: Marine Geology. New York: Wiley: 480-531.

Discusses current knowledge on submarine canyons, including examples and figures for Scripps and La Jolla canyons, and in the process, outlines the difference of opinion between the author (Kuenen), Francis Shepard, and others regarding submarine canyon formation. Kuenen notes that Shepard concludes that submarine canyons are originated, altered and maintained by several agencies with no definite decision made as to what factor is chiefly responsible, but, on the whole, favoring stream erosion (subaerial erosion) during a vast lowering of sea level in early Pleistocene times. Kuenen rejects this explanation and believes in the action of turbidity currents (submarine erosion), especially during ice ages.

Ludwick, John.C. (1950). Deep water sands off San Diego. PhD, Oceanography, University of California Los Angeles.

Cores from many of the large scale topographic depressions of the continental borderland off the California coast contain sand layers ranging in thickness up to one foot. Sand layers were examined in eighty-nine cores taken in San Diego Trough and its tributary submarine canyons. Cores were collected from the axial area of La Jolla Canyon down to 600 fathoms, the delta-shaped area at the mouth of La Jolla Canyon, and other

locations in the San Diego Trough, Coronado Bank and Coronado Canyon. Most of the layers consist of fine- to medium-grained, well-sorted, angular, quartz-feldspar sand intercalated between thicker sections of green mud. The quantitatively dominant sediment is mud. The bottom contact of the sand layers with the underlying mud usually is abrupt indicating the sudden arrival of a turbidity current. Some of the layers exhibit graded bedding indicating that the sand has settled from suspension in water. La Jolla Canyon axial cores contain a larger number of sand layers, many of them exhibiting frequent alternations with mud. La Jolla Canyon mouth cores contain many sand layers, with several short cores containing only sand. The vertical distance between alternations of sand and mud layers ranges from less than one-sixteenth inch to several inches. The grain size did not vary systematically with distance along the La Jolla Canyon axis. Grain size showed no relationship to slope of the La Jolla Canyon axis. The assemblage of heavy minerals in the sand layers of all cores is similar to the heavy mineral assemblage of the beach sand near the head of La Jolla Canyon. A core from a depth of 650 fathoms at the mouth of Coronado Submarine Canyon contains Foraminifera indicative of much shallower water, suggesting slumping or sliding of debris down a canyon-controlled course from Coronado Bank. The sand layers suggest emplacement by deposition from suspension or turbidity currents which develop in the heads of submarine canyons largely from landslides and flow along the canyon and out onto the flat bottom of the trough. This hypothesis is supported by Shepard's discovery of changes in transverse profiles across the heads of the submarine canyons and by the turbidity currents which he developed artificially in the head of La Jolla Canyon by detonating fifty pound charges of TNT. Data is given for the thickness of flow and velocity of Shepard's artificial turbidity currents.

Shepard, Francis P. (1950). Contour charts in the San Diego area. Scripps Institution of Oceanography. Submarine Geology Report No. 13. August 1950.

Contour charts are made available which cover the offshore San Diego area between La Jolla and Los Coronados Islands. These show the character of La Jolla and Coronado Submarine canyons in much more detail than was formerly available and present the topography of these canyons and of San Diego Trough on a scale which should be practical for ship operations which require exact locations. These charts show the outer extensions of the two canyons into San Diego Trough where the valleys are much less profoundly incised than in the inner gorges and where low ridges follow the valley sides. The four attached charts are based on recorded echo sounding profiles covering approximately 1,000 nautical miles off San Diego, run by Navy Electronics Laboratory and Scripps vessels, and coordinated with older less complete lines run by the Coast and Geodetic Survey in 1935 and 1937. The surveys of La Jolla and Scripps Canyons are based principally on the work at Scripps.

Shepard, Francis P. (1950). Longshore current observations in Southern California. US Dept of the Army, Corps of Engineers, Office of the Chief of Engineers, Beach Erosion Board. Technical Memorandum No. 13. January, 1950.

Currents were measured in the surf zone at frequent intervals throughout a year at a series of stations along the southern California coast from the Mexican border to Newport. The study of the data from these measurements shows that the dominant currents in the area are to the south, evidently in response to the direction of approach of the principal wave trains. North currents indicative of southern hemisphere storms prevail during a large part of the summer and fall. The feeders of rip currents were found to be important causes of longshore currents, particularly in areas with considerable submarine relief, but also in areas with straight beaches and parallel contours. Strong longshore currents exist even during times when large waves approach with their orthogonals essentially normal to the beaches. The importance of currents moving along the shore away from points of wave convergence was demonstrated by the year's investigation and has been confirmed subsequently by studies in the La Jolla area. The beach along La Jolla was studied as well as the influence of the La Jolla and Scripps Canyons offshore.

Shepard, Francis P. (1950). Beach Cycles in Southern California. US Dept of the Army, Corps of Engineers. Beach Erosion Board. Technical Memorandum No. 20. July 1950.

The large waves accompanying winter storms cause a widespread denudation of Southern California beaches. During the summer period of small waves the sand is brought back, completing an annual cycle. The beach berms vary in width with the seasonal changes so that in general they are widest at the end of summer and narrowest at the end of winter. Variation in berm width is related also to the spring and neap tides, the berms being widest during neap tides and narrowest during spring tides. The cutting back of the berms often results in scarp formation at the top of the foreshore, the scarps being most commonly developed in the fall during the first period of large waves following the small waves of summer. In addition to offshore-onshore movements of sand there are also important lateral shifts. The sand is shifted along the beach in the direction in which the waves are approaching. As a result of this lateral shift the northwest storms of winter cause the southern ends of some beaches to grow during the winter, and the southerly approach during the summer moves the sand north and therefore produces a cut. Some partially protected beaches lack seasonal changes. Certain beaches have undergone long period changes which are non-cyclinical; some of these changes are associated with engineering structures. All beaches must have a permanent loss of sand during the period of maximum cut. This loss from pocket beaches enclosed between headlands is believed to be very small since many of them have very meager sources of new sand. The more extensive open beaches, however, have a large loss of sand because of a net seasonal migration along the shore in the direction of dominant wave approach or because of sand settling into submarine canyons. In genaral this loss is replenished by new sources of sand introduced by floods and cliff erosion. Scripps Canyon is one of the examples used for this publication.

Shepard, Francis P. (1950). Mass movements in submarine canyon heads. Scripps Institution of Oceanography. Submarine Geology Report No. 17. December 1950.

Focuses on Scripps Canyon. The repetition of sounding profiles along precise ranges at the heads of submarine canyons in the La Jolla area has given a sequence of depth changes during the past three years. Changes up to a maximum of 21 feet have observed. Fill and deepening have alternated, but without any seasonal relationship such as occurs on the local beaches as a response to storm waves. The shallow valley heads are shown to shift in position and at least one new valley with a maximum depth of sixteen feet was formed during the period on an undissected slope. These changes have taken place on the sand-covered slopes inside the rock gorges and appear to be explained by sedimentation and land-sliding. The latter may be a combination of creep and sudden shifting of sediment. Sufficient material is being moved by these slides to fill the outer gorges in a matter of a few centuries, but the material is certainly being carried out of the gorges, probably going to form the sand layers in the deep outer trough at the mouth of the canyon. The canyon heads are thought to trap a large proportion of the sand which is carried along the shore by currents. This prevents the formation of sand beaches directly down from the canyons.

Shepard, Francis P. and Douglas L. Inman (1950). "Nearshore water circulation related to bottom topography and wave refraction." Transactions of the American Geophysical Union 31(2): 196-212.

The nearshore circulation in the vicinity of Scripps Beach was measured. It has been found that this circulation is controlled to a large degree by the wave convergence and divergence resulting from the diversified submarine relief outside this gently curving shoreline incorporating La Jolla and Scripps Canyons. The position of rip currents is similarly related to the points of wave convergence and divergence. The existence of strong longshore currents flowing against the direction of wave approach is established. The development of large eddies with vertical axes is discussed. Also the pulsating nature of outflowing rip currents is related to alternating groups of high and low breakers.

Shepard, Francis P. and Douglas L. Inman (1950). Nearshore circulation. Proceedings of First Conference on Coastal Engineering. First Conference on Coastal Engineering, Long Beach, Ca, San Francisco: Council on Wave Research, The Engineering Foundation. pp. 50-59.

Where canyon heads approach closely to the coast, there is striking wave convergence. At the canyon head the wave orthogonals diverge, decreasing the wave height, whereas they converge on either side, increasing the wave height. The authors

state the following for the coastline inshore of La Jolla and Scripps Canyons: it is not uncommon for the breaker height to be ten times as high north of the two canyon heads as it is inside the heads. Current measurements outside the breakers at the convergence north of La Jolla Canyon indicate a movement towards the beach from the top to the bottom. Inside the breakers the longshore currents flow away from the convergence in either direction. Rip currents commonly develop at points between the convergence and the divergence zone, where the waves are intermediate in height. The circulation pattern is primarily dependent on the wave period. The longer period waves result in a sufficient degree of convergence so that the longshore currents flow away from the zone of convergence. The circulation cell is well developed and essentially fixed in position except as shifted slightly by changes in direction of wave approach. For shorter period waves the convergence is not as pronounced and the direction of wave approach becomes the controlling factor in determining the direction of longshore currents. In this case the circulation cells are less stable and the position of the rips along the beach is variable. A strong blow accompanied by short period waves approaching diagonal to the coast produces constant current directions with the most pronounced rip at the bend in the coast in the down current direction.

Shepard, Francis P. (1949). "Terrestrial topography of submarine canyons revealed by diving." Bulletin of the Geological Society of America 60(10): 1597-1611.

To obtain more detailed information concerning the nature of submarine canyons, diving operations were carried out in the heads of La Jolla Canyon and Scripps Canyon. Frank Haymaker, who conducted 62 helmet dives starting in October 1946 under Francis Shepard's telephonic direction, described and photographed features which show that these canyons closely resemble adjacent land canyons. Haymaker found vertical and overhanging rock walls, narrow tributaries entering either at grade or as hanging valleys, and sediment-covered canyon floors. Cliffs of alluvium with layers of cobbles were discovered at the head of one of the canyons. In this article, Shepard modifies his subaerial formation hypothesis for submarine canyons by proposing that the canyons were excavated at a relatively remote time and have undergone subsequent modifications in response to glacially-controlled changes in sea level.

Shepard, Francis P. (1949). "Significance of depth changes in submarine canyon heads." Bulletin of the Geological Society of America 60: 1945 (abstract).

Using echo-sounding devices on small boats for frequent repetition of soundings along accurate ranges, a series of four deepenings, presumably mud flows, have been discovered in four different branches of the La Jolla canyons. A maximum deepening of ten feet was discovered shortly after unusually large waves. The deepening extended below the depth where waves could be reasonably be expected to have had any effect, and it is believed that waves merely acted as a trigger to set off a slide in the canyon fill.

Shoaling has taken place elsewhere, and the canyons are thought to have thick fills which may never be entirely removed by the occasional slumping of material along their floors. At the meeting from which this abstract was published, evidence was presented to indicate that the slides are common only in those canyons whose heads extend in close to the coast. The unfilled condition of canyon heads can be explained by the slides.

Shepard, Francis P. (1949). "Submarine geology and stratigraphy." World Oil 129(9): 72,74,76-77.

General article. Mentions slumping as a cause of structures and of stratigraphic traps and notes that slides or mud flows are common on slopes of the order of ten degrees. One specific mention of the La Jolla Canyon system: mentions discovery of three slumps during an eighteen month period in La Jolla and Scripps Canyons and that soundings show deepenings up to ten feet and averaging six feet over an area of at least 50,000 square feet.

Shepard, Francis P. (1948). "Diving operations in submarine canyons." Bulletin of the Geological Society of America 59(12): 1382 (abstract).

Unusual California weather in January 1948 brought a long-awaited clearing of the water in the submarine canyon heads off La Jolla. Photographs taken by Frank Haymaker on the steeply sloping floor of Scripps Canyon show the vertical rise of stratified rock above a floor deposit of muddy sand with great masses of kelp. In places the photographs show overhanging rocks jutting out from the walls. The vertical ridge between a tributary entering the main canyon at grade is shown in a photograph and a hanging valley can be seen. Along the side of the canyon fill there is a small gutterlike depression, presumably due to slumping. In La Jolla Canyon, a ridge of an alluvial cobble formation is shown with precipitous walls rising above the floor of a gully. Elsewhere a large boulder of clay was found at the foot of a tributary valley where its gradient flattened near the juncture of the main valley. The photographs and description by the diver of the canyons show such complete agreement with the land canyons in the near-by cliffs that the conclusion is almost inescapable that the submarine canyons were formed by the same cause -- subaerial erosion.

Shepard, Francis P. (1948). "Evidence of world-wide submergence." Journal of Marine Research 7(3): 661-678.

Proposes that submarine canyons are essentially the same the world over, discounts a marine origin for them and proposes a subaerial (river eroded) origin. Discusses evidence of a very general submergence of continental borders and states that the most completely studied submarine canyons have proved to be identical in character

to the land canyons which are directly inside. Frank Haymaker of SIO has dived into and explored the head of two canyons at La Jolla. He found typical stream erosion features, such as staircase canyons with waterfall drops, hanging valleys, tributaries entering at grade, vertical and even overhanging rock walls, and cobble covered floors. The canyons on land inside have all of these same features.

Shepard, Francis P. (1948). Submarine geology. New York: Harper & Brothers.

Proposes that submarine canyons were eroded by rivers (subaerial formation) and are now submerged (sea level was much lower in relation to land long ago).The sea level was much lower in relation to land long ago. Canyons are closely similar to land canyons in various features. Continental slopes without canyons would be easily eroded by rivers if raised above water. If canyons had submerged recently, they would head into deep estuaries such as those on the west side of Corsica but if the submergence had occurred thousands of years ago, the coasts might have been straightened and cut back inside the majority of the canyons. Numerous valleys submerged at a remote period would have been filled by subsequent marine deposition and this filling would have taken place particularly on the gentler submarine slopes which is what is found. Continental slopes which were formed recently by fault movements should lack the canyons which is the case. The largest and deepest canyons are found off large rivers. No significant difference in character has been noted between canyons which extend into estuaries and canyons which head well out on the shelf or even on the continental slope. The probability that large canyons are cut into late Tertiary formations leaves little time available for their formation by a slowly acting submarine process and suggest that they were formed by some rapid process such as subaerial river formation. Streams are the only agents capable of cutting profound canyons into the hard rock found on some canyon walls. A problem of this subaerial hypothesis is the necessity for a short-period emergence of all or most of the continental slopes to a height of at least six thousand feet and a subsequent submergence. The emergence is hypothesized by withdrawal of oceanic water into great Pleistocene icecaps, coupled with a compensatory isostatic upwarping of the continental margins. Has brief mentions of La Jolla and Scripps Canyons.

Shepard, Francis P. (1948). "Detailed studies of submarine canyons at La Jolla, California." Geological Society of America Bulletin 59(12): 1351 (abstract).

Emery, K.O. (1947). "Asymmetrical valleys of San Diego County, California." Bulletin of the Southern California Academy of Sciences 46(2): 61-71.

Asymmetry of terrestrial valleys cut through a marine terrace in San Diego County was measured for many valleys having various gradients and directions of drainage. Comparison of results with those to be expected from each of the various causes of asymmetry cited in the literature lead to the conclusion that the more abundant vegetation on shady slopes is sufficient to partly protect the shady slopes from erosion, whereas erosion progresses unimpeded on the sunny south-facing wall slopes. This is supplemented by uniclinal shifting in the direction of the regional dip, which, in most of this region, would also tend to form steep north-facing walls. Inasmuch as vegetation and uniclinal shifting should produce approximately similar results, it is difficult to determine their relative effectiveness; however, in a few small areas where lateral shifting alone would develop steep south-facing walls, the north-facing walls actually are steeper, probably indicating the greater effectiveness of vegetation. Fairly detailed contour charts of Coronado, La Jolla, Scripps, and Carlsbad Submarine Canyons have been made. Preliminary examination of their side slopes suggested systematic asymmetry and provided incentive for this investigation as a means of learning more of their origin. Later and more careful study of the symmetry indices measured from the submarine contours and also from sounding lines crossing the canyons revealed some asymmetry, but typically the walls have about equal slopes. The gradients of the submarine canyons are steep, however, and the symmetry of the side slopes corresponds with that of land valleys of equally steep gradients.

Munk, Walter H. and Melvin A. Traylor (1947). "Refraction of ocean waves: a process linking underwater topography to beach erosion." Journal of Geology 55(1): 1-26.

Waves out at sea, though usually forming a complex pattern, have essentially the same characteristics over large distances. Wave crests approaching a coastline at an angle tend to swing parallel to shore. This happens because the wave velocity decreases as the depth decreases, so that the portion of the crest nearer the shore moves slowly while the portion of the crest in deeper water races ahead. Upon entering shallow water, these waves are transformed under the influence of bottom features, and such transformations may be so marked that breaker heights may vary greatly over short distances along the shore. The effect of bottom features upon waves can largely be interpreted in terms of wave refraction. In turn, wave refraction may be responsible for alteration of the bottom features by accumulation or removal of sediments and be an important factor in beach erosion. The mechanism of refraction is illustrated for several examples including a submarine canyon. Portions of wave crests over the center of a submarine canyon are in deeper water and move ahead faster than the portions on either side. Consequently, the waves fan out, resulting in divergence (low waves) over the head of the canyon and convergence (high waves) on either side. The wave crests bend sharply over canyon walls. Variations in wave height can be recognized by the prominence of the wave crests on either side of the canyon compared to the crests directly over the canyon and by the variation in the width of the surf zone. The steep walls on the North Branch of Scripps Canyon cause a section of the crest to be bent through ninety degrees. This section travels north along the coast and intersects the regular wave

train in a crisscross pattern. Wherever the refracted crests intersect the main wave train, a hump on the sea surface is formed, the height of which equals the sum of the height of the two intersecting waves. Judging from this article's illustrations, these larger waves appear to come ashore at the Black's Beach point break. The wave climate at La Jolla is characterized: (1) winter waves generated by cyclones originating at the east coast of Asia and moving along the usual cyclone path into the Gulf of Alaska - long period swells of 11-15 seconds with heights of 3-7 feet; (2) winter waves generated behind cold fronts coming into the coastal region - short period swells of 7-10 seconds with heights of 4-12 feet and usually coming from a W to NW direction; (3) summer saves generated by winds in the northeast periphery of the Pacific High - swell period of 6-9 seconds and height of 2-5 feet coming from WNW to NW; (4) summer waves generated in the Southern Hemisphere - the "southern swell" with period of 13-20 seconds and height of 3-5 feet coming from S to SSW; (5) spring wind waves generated in local low-pressure regions - swell period is 5-7 seconds and heights of 10-15 feet generated from NW or NW winds. Extreme variations in breaker height along the beach north of La Jolla can be computed for typical swell conditions, taking the complex local bottom topography and the orientation of the coastline into consideration. These changes are computed from refraction diagrams for typical swell conditions, and they compare favorably with observed changes in wave height, thus indicating that wave refraction is the primary mechanism controlling changes in wave height along a beach and that friction, diffraction, and other processes can be of secondary importance only. Transportation of sediments is dependent upon longshore current, rip currents, and horizontal diffusion and that all these factors are greatly influenced by the existing refraction pattern.

Shepard, Francis P. (1947). "Diving operations in California submarine canyons." Bulletin of the Geological Society of America 58: 1227 (abstract).

The walls of Scripps Canyon are rocky, but coated to a considerable extent with marine growths. Cliffs and even overhanging slopes are found in many places. The canyon walls are cut by tributaries, and some of these tributaries enter the main valley as hanging valleys. Scripps Canyon is closely similar to land canyons which are directly adjacent to it. The canyon bottoms are narrow and largely choked with kelp and muddy sediments, although rock outcrops are found sparingly. The decomposition of the kelp may assist the development of the mud flows which are thought to keep the canyons from being filled. La Jolla Canyon has much less rock exposed at its head than Scripps Canyon. The steep muddy slopes at the head of this canyon are interrupted in places by vertical cliffs of alluvium which include layers of cobbles. Also reports on problems with using underwater photography for studying the canyons.

Emery, K.O. and Francis P. Shepard (1945). "Lithology of the sea floor off southern California." Bulletin of the Geological Society of America 56: 431-478.

La Jolla Canyon walls have rock outcrops, some of them Cretaceous and some Eocene, It is cut along a fault between Eocene rocks to the north and Cretaceous rocks to the south.

Shepard, Francis P. and K.O. Emery (1941). Submarine topography off the California coast: canyons and tectonic interpretation. Baltimore MD: Waverly Press.

Concludes that the submarine canyons were eroded by streams during the emergence of the continental shelf and part of the continental slope (subaerial formation hypothesis). Describes the La Jolla and Scripps canyon system, origin, changes and shifts in heads, etc.

Shepard, Francis P., K.O. Emery and Eugene C. LaFond (1941). "Rip currents: a process of geological importance." Journal of Geology 49(4): 337-369.

On page 366-367, discounts whether rip currents are the cause of submarine canyons or keep them clear of sediments. Among other points, mentions that rip currents in La Jolla are much less pronounced around the head of La Jolla Canyon then they are on either side (page 357-8). Does state that it remains to be seen if rip currents play a role in canyon development or clearing during unusually large wave periods.

Shepard, Francis P. and Eugene C. LaFond (1940). "Sand movements along the Scripps Institution pier." American Journal of Science 238: 272-285.

Sand is cut away from the beach and foreshore during the stormy winter and is deposited largely within one thousand feet of the shore. The sand is returned landward during the calm seas of the succeeding summer. Outside the pier at a distance of three thousand feet is a submarine canyon running diagonally to the coast and another canyon extends almost to the beach a mile south of the pier. The sand along the pier is not directly influenced by the canyon since the sloping bottom which extends along the pier is not terminated by the canyon but is bordered by a narrow twenty fathom terrace which separates this slope from the canyon.

Sverdrup, Harald Ulrik (1940). "Research within physical oceanography and submarine geology at the Scripps Institution of Oceanography during Apr. 1939 - Apr. 1940." Transactions, American Geophysical Union 26: 343-346.

Revelle, Roger and Francis P. Shepard (1939). Sediments off the California coast. IN: Recent Marine Sediments, a Symposium. P. D. Trask. Tulsa, Oklahoma: American Association of Petroleum Geologists: 245-282.

Discussion includes California submarine canyons including La Jolla Canyon. Samples have been collected by Shepard and others from sixteen canyons and most of these samples were analyzed by Cohee (Journal of Sedimentary Petrology 8:(1)19-32, 1938). Near the heads of the canyons the sediments from the canyon bottoms are commonly finer than those from the walls and the adjacent shelves. The samples from all three of these environments have median diameters which lie close to the line between very fine sand and silt (62 microns) but there is commonly some increase in silt within the canyons. The difference however is not very striking and there are many exceptions. Analyses of many of the canyon samples yielded median diameters equivalent to coarse sand whereas pebbles and rock fragments were discovered in some places in the bottom of ... and La Jolla canyons. The situation is further complicated by the discovery of ledge rock in dredging up the sides of the canyons and along their floors. Cores and dredgings from the floors of the relatively shallow Southern California canyons indicate that for the most part the sediments in their outer portions are as coarse as at the canyon heads. A core from 185 fathoms in La Jolla Canyon consisted of sand as coarse as that found on the beach inshore (analyses by KO Emery)....Probably a partial explanation for the sporadic occurrence of coarse material and the irregular texture distribution in the canyon sediments comes from the existence of landslides and mud flows, the occurrence of which has been demonstrated from observations of changing depths in the canyon heads.....One of the most difficult problems is to obtain evidence concerning the movement of sediment over the bottom.... some data have been obtained by traps and further evidence of the shifting of sediments comes from changing depths near shore or from the discovery of changing types of bottom. A number of sediment traps of a type designed by KO Emery, containing compasses to show the direction of the trap on the bottom, were placed ... in submarine canyon heads in January, 1938. One from 30 fathoms in La Jolla Canyon was recovered at the end of March. An abundance of sediment was found in the various trays. Core samples from the same locality showed that the trap sediment was finer than that of the surrounding sea floor. Analyses of the materials deposited showed that the median diameters varied between 33 and 88 microns, whereas the bottom sediments in the same area averaged 110 microns in diameter. During the two months period in which the apparatus was in place, the top of the trap, which was designed to receive only sediments settling more of less vertically, was covered by a layer nearly two millimeters thick of brown sandy silt. A series of trays on the four sides of the trap, arranged so as to catch material swept along the bottom, received a layer averaging about 0.5 millimeter in thickness. The average diameter of the material in the top was 41 microns as compared with 75 microns for the bottom group of side trays. The compass showed that the largest median diameters were found in the trays which faced up and down the canyon. The reddish brown color of the material in the trap was in contrast with the usual olive-green color of the bottom sediments in this area. However the top of the core collected at the same time was also brown. Moreover this top part was finer-grained than the lower green portion. The brown color probably

represented the oxidized material carried into the sea during the Southern California flood of March 1938 which preceded the pulling in of the trap..... The frequent repetition of accurately located sounding lines across the heads of canyons has shown that over short periods there may be a very rapid fill....The fact that the canyons remain open necessarily implies that this fill is only temporary and that after a period of accumulation the new sediment must move outward probably in the form of a mud flow or slide. Such slides have actually been observed by repeated soundings in La Jolla Canyon. The finding of sandy and even rocky bottom in the outer portions of the canyons shows that bypassing is not confined to the canyon heads. Samples taken in the outer part of La Jolla Canyon in 1933 consisted of sandy silt, but a core taken in the near vicinity in 1938 consisted of fine sand.

Shepard, Francis P., Roger Revelle and R.S. Dietz (1939). "Ocean-bottom currents off the California coast." Science 89(2317): 488-489.

Reports data for La Jolla Canyon, Scripps Canyon, and some other canyons. An Ekman current meter was suspended at distances between 125 and 20 centimeters above the seafloor. In La Jolla Canyon over silty sand at 42, 235, and 560 meters, maximum velocities were observed (respectively) of 7.3 cm/sec (14 observations), 20.4 cm/sec (21 observations), and 23.0 cm/sec (6 observations). In Scripps Canyon at 182 meters, a maximum velocity of 14.7 cm/sec (6 observations) was observed. The maximum velocities of bottom currents are of the same order of magnitude as most surface currents in the open sea. The velocities are not comparable with those found in rivers on land nor in narrow tidal passages since they do not exceed 37 centimeters per second. The maximum current velocities observed in deep water were as high as those found in shallow water. The observations do not show any significant relationship between maximum current velocities and the different types of bottom topography, nor is there evidence to indicate that the currents are stronger where the bottom is sandy or rocky. It became evident that both the speeds and directions of the currents were constantly shifting. A considerable number of observations showed the absence of a velocity strong enough to make a record (less than 2 or 3 cms per second). Such periods were occasionally followed by some of the highest measured velocities. The observed directions of movement showed a tendency to follow the axes of the canyons, but shifts in direction from up to down canyon occurred at irregular intervals. The bottom currents thus appear to be non-tidal in character, although they exhibit some tidal components. Even on the continental shelf where tidal components might be expected to predominate, non-periodic changes in velocity were encountered. The observed irregular movements of the bottom water probably can be best interpreted as indicating the presence of large moving eddies with vertical axes. The presence of silts and muds on the bottom in certain areas of highest observed currents indicates that these eddy currents are not competent to prevent all deposition. Nevertheless, such currents must play an important part in the transportation of fine sediment along the sea floor. Since evenly distributed eddies can not alone produce any net transport, however, other factors such as the gravitational component down slope and residual currents must cooperate to prevent deposition on the

many areas of hard bottom off the California coast. Possibly, also the currents are not as competent to move debris as might be expected from observations on the transporting power of rivers, since it is probable that velocities decrease more rapidly near the sea bottom than near the bottoms of rivers. These bottom currents may be looked on as part of a mechanism for carrying sedimentary material, brought into the ocean by floods or by wave erosion, out into considerable depths of water. This transporting ability however should not be thought of as equivalent to cutting power sufficient to erode great submarine canyons out of the rock of the ocean bottom.

Cohee, George V. (1938). "Sediments of the submarine canyons off the California coast." Journal of Sedimentary Petrology 8(1): 19-33.

Doesn't report data specifically on Scripps Canyon though Scripps Canyon is mentioned in the article abstract as having bed rock cropping out on its side. The sediments in the numerous submarine canyons off the California coast may be characterized as sand, mostly fine sand, with an abundance of silt and some clay. They are in general very well sorted. Medium to coarse sand is found very near shore at the canyon head; farther out in the canyon there is a rapid decrease in the sand content of the sediment. In the outer part of the canyons the material is largely silt with sand and clay. The character of the sediments suggest that the fine material carried into the canyons settles out in the deeper portions and on the continental slopes. Rock fragments and boulders have been dredged from many canyons. Bed rock crops out on the sides of Monterey, Carmel and Scripps canyons. The median grain sizes in the canyons are slightly lower than on the adjacent parts of the shelf. There are variations in median grain sizes in the canyons but there is not always a decrease in median grain size with increasing depth. Heavy minerals make up only a very small part of the sediments. Authigenic minerals and organic material are common in the deeper portions of the canyons. The calcium carbonate content increase with depth due to the increase in abundance of organisms.

Shepard, Francis P. (1938). "Submarine canyons off the California coast." California Journal of Mines and Geology 34(3): 298-310.

Reviews what is known about California submarine canyons, including a depth profile of Scripps Canyon. Discusses theories of submarine canyon formation.

Shepard, Francis P. and Charles N. Beard (1938). "Submarine canyons: distribution and longitudinal profiles." Geographical Review 28(3): 439-451.

Reviews worldwide submarine canyon distribution and longitudinal profiles including Scripps Canyon.

Sverdrup, Harald Ulrik (1938). "Research within physical oceanography and submarine geology at the Scripps Institution of Oceanography during April 1937 to April 1938." Transactions, American Geophysical Union: 238-242.

Shepard, Francis P. (1937). "Shifting bottom in submarine canyon heads." Science 86(2240): 522-523.

Soundings along two sections of Scripps Canyon were made in 1935 and 1937 showing decreasing depth, indicating that there had been fill in of the canyon. Several tentative conclusions: canyon heads receive sediment from time to time but remain unfilled because this sediment is subsequently removed. The cause of the removal must be submarine slip or mud flow. Channels at the head of canyons appear subject to some moderate shifting in position. Data indicates that depth shifts are not transmitted extensively down the canyon but the shifting at the head may be more frequent and rapid whereas there may be shifting of sediment at depth at long intervals. Further data is needed to tell to what extent the deepenings are the result of unusually large waves and to what extent they are due simply to the flowing of muddy sediments down the canyon floor when the sediments have been deposited to such an extent as to exceed the angle of rest.

Shepard, Francis P. (1936). "Continued exploration of California submarine canyons." Transactions of the American Geophysical Union 17: 221-223.

Dredged rocks from the side of La Jolla Canyon. The dredged rock is assigned to the Eocene by comparison with the nearby formations on land. This shows that the canyon must have been cut out of rock and is not a non-depositional feature kept open by currents while deposition was proceeding on either side nor could it be the result of muddy currents flowing down the continental slope. Soundings were run on the shallow La Jolla Canyon head which had deepened since previous soundings.

Shepard, Francis P. (1934). "American submarine canyons." Scottish Geographical Magazine 50: 212-218.

General review of submarine canyon knowledge to date . Has one figure (Figure 4) of "a section across a submarine canyon off La Jolla" showing depth and width of the canyon at that section. No specific canyon location given for the section. Depth of canyon section starts at 55 meters and drops down to 190 meters, going from a canyon width of 220 meters down to 20 meters at the bottom of the section. There is a near vertical drop from 85 meters down to 150 meters on one side of the canyon section. The

text referring to the figure discusses submarine canyon formation theories. As supporting evidence to negate universal formation by submarine currents, the author states that he has obtained many angular fragments of rock from the sides of canyons and has found slopes so steep as to indicate rock cliffs.

Shepard, Francis P. (1934). "Detailed surveys of submarine canyons." Science 80(2079): 410-411.

Describes depth sounding methodology used by Shepard in La Jolla and Carmel Canyons. Found very steep slopes in La Jolla Canyon where a maximum of 84 degrees was measured on a two hundred foot cliff. Outward from the La Jolla Canyon head, each survey section showed an increase in depth with no evidence of enclosed basins. Terraces, probably of rock, were found on the sides of La Jolla Canyon. Tributaries entering at grade were found in La Jolla Canyon.

Davidson, George (1897). "The submerged valleys of the coast of California, U.S.A., and of Lower California, Mexico." Proceedings of the California Academy of Sciences 1 (Third Series, Geology): 73-103, plates.

Author describes as follows: The Soledad or La Jolla Valley. This valley heads southeastwardly into the slight recession of the shore-line on the north side of Point La Jolla. This point is the northern extremity of an almost isolated sandstone hill named Soledad, lying between the northern part of False Bay [Ed note: now known as Mission Bay] and La Jolla. The extent of the hill is about three and one half miles NW and SE, and very nearly as wide ENE and WNW. The ocean front is a three mile stretch of rocky, jagged shore, rising rather sharply to over eight hundred feet in one and one half miles. The higher part of the hill is to the WNW. There is no very marked depression between this hill and the high land to the NNE; certainly nothing to indicate a submerged valley. The head of the valley is within one third of a mile of the deepest part of the small cove, and carries 25 fathoms to within 150 yards of the three-fathom line. From its head it stretches three miles N 40 degrees W, to the 225 fathom curve, and then two and one half miles N 70 degrees W, to the 300 fathom curve, beyond which there are no immediate soundings. The valley is quite narrow out to the 200 fathom curve. On the south side of the valley the 500 fathom line lies three miles broad off Point La Jolla, and thence the soundings deepen rapidly seaward, but to the southward the 50 fathom plateau increases in breadth to five miles off False Bay. North of the valley the 500 fathom line is barely two miles off shore and parallel therewith for seventeen miles; outside this narrow plateau the water deepens rapidly to 200 fathoms. The greatest observed depth is 297 fathoms at five and two thirds miles from the beach, and about where the normal 120 fathom line would pass. The fine dark gray sand of the bottom extends outward to about 25 fathoms. There is green mud and fine sand, with added broken shells, on the NE and SW slopes of the valley in 100 fathoms; at 150 fathoms, green mud alone. Approaching the head in

115 fathoms there is green mud and fine sand; and at the nead in 25 fathoms hard bottom, which may be sand or rock. The geographical position of the head of the valley at the 25 fathom curve is: Latitude 32 degrees 51 1/4 minutes N; longitude 117 degrees 16 minutes W. Plate IV shows Soledad Submerged Valley [Ed note: now known as La Jolla Canyon; Scripps Canyon is not mentioned or illustrated and is obviously unknown to the author].